Pests and poverty: the continuing need for crop protection research

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The DFID Crop Protection Programme (CPP) is one of 11 research programmes funded by the Department for International Development (DFID). The CPP commenced in 1995 with the broad objectives of eliminating poverty and enhancing sustainable livelihoods in developing countries through the development, application and promotion of research outputs on socially and environmentally acceptable crop protection technologies. The CPP is managed by Natural Resources International Ltd. Further information about the CPP can be obtained from the Programme Manager (Tel: +44 1634 883366) or at http://www.nrinternational.co.uk.

The UK Department for International Development's *White Paper* and *Strategies for Achieving the International Development Targets*[1] recognize that knowledge and technology underpin development and that the elimination of poverty, improved economic growth and protection of the environment can be achieved through support for research and development that enhances the sustainable livelihoods of poor people. This philosophy is also the foundation of the Consultative Group on International Agricultural Research (CGIAR) future strategy, *A New Vision for 2010*.[2] The DFID Crop Protection Programme (CPP) is committed to the development and promotion of socially and environmentally acceptable management technologies to reduce crop losses from pests[3] in developing countries. Improved pest management is an essential part of a holistic approach to crop improvement, substantially contributing to poverty elimination, enhanced livelihood security and reduced environmental degradation. This article reports the progress being made in the development, application and promotion of a broad range of pest management technologies that farmers are adopting, especially in South Asia and Sub-Saharan Africa, home to most of the world's poorest people. Without the advances made by agricultural research, including crop protection technologies, during the past 30–40 years, the effects of poverty would have been far worse. Further support is essential to meet the challenges of producing even more food from even less land using technologies that have minimal adverse environmental impacts and that contribute to poverty elimination. Technologies such as host plant resistance, judicious use of pesticides, biological control and integrated pest management will have an increasingly important role to play in the future.

Poverty defined

Poverty is the denial of opportunities and choices most basic to human development.[4] Denial may be due to lack of capital assets including financial resources; natural and physical resources (eg food, land, equipment, water, energy, shelter); education, skills and labour; social resources (eg networks, organizations, political power); or any combination of these factors.[5] Poverty includes hunger, loneliness, deprivation, discrimination, abuse, illiteracy and many other deficiencies and limitations.

Lack of income and food are sound quantitative criteria for identifying the poor and their level of poverty or well-being.[6] Food is the most fundamental human need. Meeting basic food requirements is the first priority of the poor, who may spend up to 80% of their income on food.[7] Ensuring food entitlement is a major priority in most national policy frameworks for poverty elimination.[8] Improvements in food crop productivity are essential for both national and household food security and for continuing to contribute to the elimination of poverty.

Raising overall food production and productivity should be addressed in the early stages of a sequential process for eliminating poverty.[9] Continued agricultural growth is a necessity, *not an option,* for most developing countries.[10] However, poverty elimination requires not only improvements in the provision of basic needs and services to the poor, but also the creation of an enabling environment, which encourages economic growth while reducing degradation of the natural resource base. Protection of the environment and the natural resource base *does not negate* the need for continuing to contribute to agricultural development, poverty elimination and increased food security. Continued investment in agricultural research, including crop protection research, is needed to generate technologies that will contribute to both the basic needs of the poor and to economic growth.

Who are the poor?

The poor are a very heterogeneous group: they are classified by location (rural or urban); role (producer, labourer or consumer); gender (male or female); ethnic group; source of livelihood; level of resources or capital assets.[11] Poverty is also a process and the poor are a moving target, shifting in and out of different poverty levels over time.[12] The poor may be producers, consumers, labourers, or all three categories at once. As producers, poor farmers may gain from increased yields and profits as a result of new technologies provided by crop protection research. As consumers, the rural and urban poor may gain from more reliably available, cheaper, safer, higher quality food produced through environmentally friendly pest management strategies. When food prices decrease and stabilize, the poor gain proportionately more than the rich. As landless agricultural labourers, the poor may gain from increased employment opportunities as a result of increased production and more labour-intensive technologies (but not necessarily higher wages). They may also gain from improved health due to safer management technologies, such as crop varieties with pest resistances which need fewer or no pesticides.

The demography of the poor

The proportion of different categories of poor has changed considerably over the past 40 years.[13] In the 1960s, the majority of the poor were small-scale farmers. Due mainly to population growth, this balance has changed. Today, the largest category of poor consists of rural, landless labourers. Roughly 70% of the poor in developing countries are still located in rural areas.[14] However, over the next 20 years, due to increasing urbanization (the world's urban population is expected to double to 3.6 billion), a considerable shift in this balance is again expected in developing countries, as more and more poor people move to cities.[15] For instance, in Sub-Saharan Africa, it was predicted that 40% of the poor would live in urban centres by 2000.[16] A recent study of urban and rural poverty in eight developing countries showed that in five of those countries the proportion of urban poor was increasing over time.[17] The rural landless labourers will probably be the first to move, swelling the ranks of the urban poor, thus increasing the food needs of urban consumers. Alleviating urban poverty may require different strategies from those for rural poverty.

Whereas agricultural research, including crop protection research, can generate technologies that directly help the poor producer and the poor consumer, it is much more difficult to steer the benefits of such research directly towards the poor labourer[18] through enhanced employment opportunities (although all labourers will benefit as 'consumers'). Poor landless labourers, who rely solely on employment income to buy food, will benefit from increased use of improved varieties[19] and hybrid seed production,[20] which demand higher labour inputs, as well as through increased farm and village level post-harvest processing opportunities. However, they may be adversely affected by other new technologies such as labour-saving weed management practices (eg pre-emergent herbicides; herbicide-resistant crop varieties). They are also highly vulnerable to changing policy and economic environments, which are subject to a complexity of influences far beyond the direct reach of crop protection research.[21]

The importance of agricultural research in poverty elimination

Agriculture is the most important activity in most developing countries. Over 60% of the economically active population and over 50% of the rural economy are involved with agriculture. Much of the increase in food production globally during the past 40 years can be attributed to research, including crop protection research, with internal rates of return (IRR) of 30–50%.[22] Agricultural research has a high poverty elimination pay-off:[23] for example, the return on investment in rice research in Bangladesh from 1980–94 was 36:1). It has played a key role in the overall economic development of many countries.[24] Agricultural research is 'the best hope — the only hope — of winning the race between population and food'.[25] This view is supported by millions of resource-poor farmers who have adopted high yielding varieties (HYVs) with improved pest resistance.[26]

A recent study by IFPRI[27] showed that additional government spending on roads and agricultural research and development had the largest impacts on poverty reduction and productivity growth in rural India (Figure 1). In contrast, government spending on rural development and employment programmes, spending specifically targeted at poverty reduction, had only a modest effect on alleviating poverty (the poverty line was defined as Rs49 per month at 1973/74 prices). This study shows that targeting government expenditure simply to reduce poverty is not sufficient in itself. Government expenditure also needs to stimulate economic growth, the only sure way

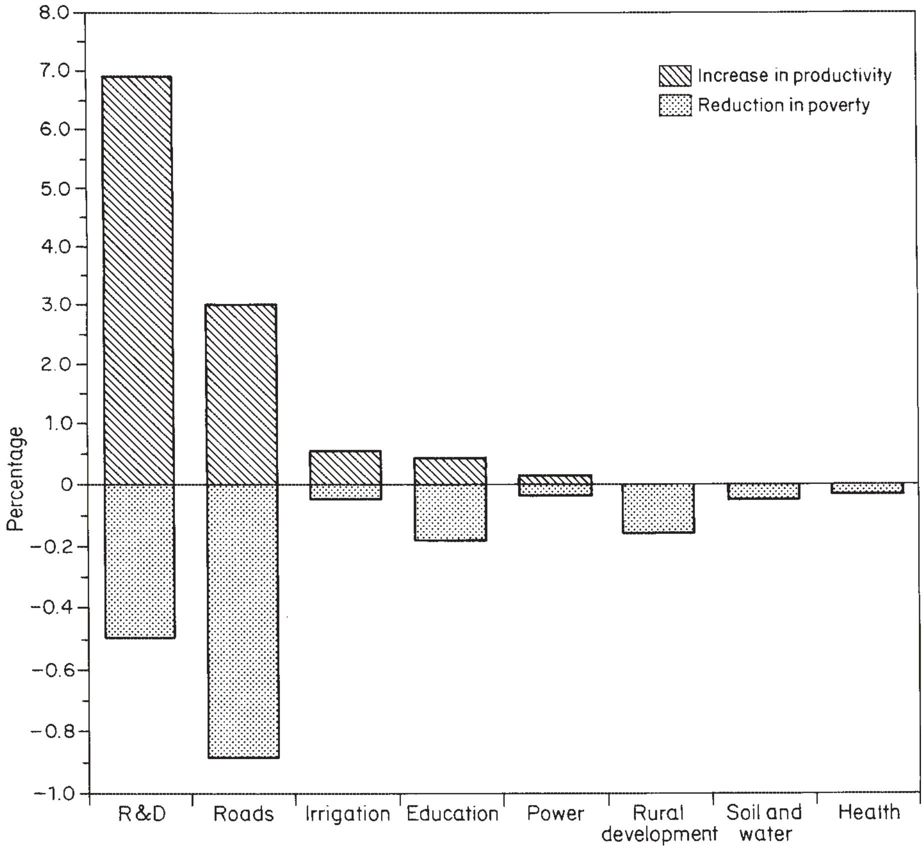

Figure 1. Increases in growth of productivity and reduction in poverty as a result of additional government expenditure in rural India.
Source: S. Fan, P. Hazell and S. Thorat, *Linkages Between Government Spending, Growth and Poverty in Rural India*, IFPRI Research Report No 110, IFPRI, Washington, DC, 1999.

of providing a sustainable solution to rural poverty and of increasing the overall welfare of rural people.[28]

Agricultural research can reduce poverty through increasing food production, food access and consumption, employment and economic growth. Food production has tripled in the past 40 years, outpacing population growth.[29] History records no increase in food production that is remotely comparable in scale, speed, spread and duration. The economic impact of improved agricultural technologies benefits:

- producers, through increased productivity and/or greater profitability;
- labourers, by generating employment and improving health;
- traders, transporters and local food processors, by providing an assured supply of the product; and
- consumers, through increased availability and quality of food and lower prices.

Crop losses due to whatever reason negatively affect all categories of the poor. The reduction of losses from pests in both food and cash crops is an integral part of the successful application of agricultural technologies. However, it is difficult to attribute a level of poverty reduction to a specific technology, eg a new pest management technology, especially when it is a small, but critical component of a larger, multidisciplinary collaborative effort to improve national, regional or global food production.

Without agricultural research, including crop protection technologies, increasing food production, reducing food prices and generating employment income over the past 30–40 years, poverty would have been far worse: many of the world's poor would have been poorer and millions alive today would have died of famine or long-term malnutrition.[30] In India alone, the government's investments in agricultural research in the 1970s, together with farmers' efforts to raise food crop yields, pulled millions of people out of poverty (poverty declined from 55% to 33% between 1973 and 1993) and averted predicted famines.[31]

The need for crop protection research in poverty elimination

Pests, crop losses and society

The locust plagues and wheat rust epidemics graphically described in the Bible are a stark reminder of the devastating effects of insect pests and fungal pathogens on crop production and the consequent misery and poverty.[32] History is rich in examples of the effects of crop failure due to diseases on society. The Irish potato famine of 1845–46 caused by late blight (*Phytophthora*

Table 1. Effects of crop pest epidemics on society — some examples.

Pests	Effects
Wheat rust epidemics in India (1850–1950)	Starvation: 27 major famines
Potato leaf blight in Ireland (1845–46)	Starvation: 3 million people died
Rice brown leaf spot in Bengal (1942–43)	Starvation: 2 million people died
Groundnut rosette virus disease in Sub-Saharan Africa (1900 to present)	15 epidemics in Sub-Saharan Africa with losses of up to £200 million per epidemic
African cassava mosaic virus disease in Uganda (1990s)	60,000 ha of cassava worth £40 million lost annually
Locust plagues of Sub-Saharan Africa	Widespread starvation
Rice, sorghum and maize insect pests in developing countries	10–35% yield losses annually
Cassava insect pests in Sub-Saharan Africa	20–80% yield losses annually
Weeds of cotton, rice and maize in developing countries	20% yield losses annually
Striga in Sub-Saharan Africa	40% of arable land infested

infestans);[33] the Indian wheat leaf and stem rust epidemics of 1850–1950 (*Puccinia* spp.);[34] the great Bengal rice famine of 1942–43 associated with a devastating epidemic of brown spot (*Biploris oryzae*);[35] and 15 serious epidemics of groundnut rosette in Sub-Saharan Africa since the early 1900s[36] are a few past examples that caused severe hardship for small producers with consequent effects on poor consumers and labourers (Table 1). Recent examples include the African cassava mosaic virus epidemics in Uganda[37] and the epidemic of sorghum ergot in Latin America.[38]

Annual losses due to insect pests in rice and major cereals in developing countries have been estimated at 10–35% annually[39] (Table 1). Insect pests constitute one of the major biotic constraints limiting rice production, and on a global scale £2.5 billion is spent on pesticides to control them.[40] In the 1970s in many parts of Africa, 80% crop losses in cassava due to mealy bug (*Pheococcus manihoti*) were reported, while in the 1980s in parts of Uganda, crop losses in cassava due to green mite (*Mononychellus tanajoa*) and African cassava mosaic virus disease were more than 50%.[41] Such serious losses due to insect pests have severely affected all categories of the poor.

Globally losses due to weeds are roughly 10–15% of attainable production of the principal food and cash crops,[42] with developing countries being burdened by the greatest losses. Some 18–20% of cotton, rice and maize is estimated to be lost due to weeds in developing countries of Africa, Asia and the Americas, compared with 9–11% in the industrialized economies of these areas[43] (Table 1). It is estimated that 40% of the arable land in Sub-Saharan Africa is infested with *Striga* spp., considered to be the greatest biological constraint to food production in Africa[44] (Table 1). In Sub-Saharan Africa, it is estimated that women often spend up to 80% of their working hours weeding.[45] In semi-arid areas of Zimbabwe, weed control accounts for up to 60% of the labour used in maize production.[46]

Even with the significant advances in crop protection research during the past 40 years, up to 30% of pre-harvest crop yield is lost annually due to pests. Without protection, and especially in developing countries, these losses are often more than 50%. Pest populations are also dynamic, responding to new environments and selection pressures — sometimes imposed through the misuse of protection practices — by evolving new, often more damaging variants. Continued crop protection research is essential to keep pace with these changes by extending and improving existing successful technologies and developing more robust technologies to meet future challenges.

An enabling environment

Pest damage reduces:

- yield and quality of crops and profits for poor producers;
- employment opportunities for poor labourers, traders, transporters and processors; and
- food entitlements for poor consumers, thus increasing poverty.[47]

Pest problems add to producers' risks and divert resources from other priorities (eg school fees, medicines, inputs for cash crops) if pest control inputs have to be purchased or if time needed for other activities is diverted to pest control practices (eg weeding). Crop failure due to pests will reduce both the availability of and direct entitlement to food for the poor. An individual farm family will starve because of the direct loss of food, loss of income, inability to repay debts, no money or credit to buy inputs for the next cropping season, etc.[48] This initiates a downward spiral from which it is very difficult for the family to escape. If the crop failure is widespread — not unusual for pest outbreaks such as locust plagues or wind-dispersed pathogens — not only will producers move into abject poverty, but those groups who depend on producers for their entitlements, eg the agricultural labourers, traders, transporters and processors, will also suffer. The key to reducing poverty therefore lies in establishing an enabling environment to ensure food availability and guarantee food entitlement.[49]

Contributions of crop protection research to poverty elimination

Since the beginnings of agriculture, farmers have developed a very wide range of farming practices that contribute either directly or indirectly to pest management, eg sanitation, seed selection, rotation, weeding, multiple cropping, tillage, fire, flooding, natural pesticides, etc (see Thurston[50] for numerous examples), many of which are still used successfully today. From 1900 onwards, and especially in industrialized countries, pest control was increasingly based on chemical pesticides, which, when abused, led to pesticide resistance and destruction of parasites and predators. Since the 1970s, host plant resistance has been increasingly successful in controlling many important pests of staple food crops, with substantial and continuing benefits to both small poor farmers and the environment. Also, the value of natural and enhanced biological control is increasingly being realized and developed as the backbone of many successful integrated pest management (IPM) programmes.

Improved crop protection strategies will contribute to reducing poverty and improving livelihood security in developing countries, mostly by ensuring food availability and partly by guaranteeing food entitlement in several ways:

- increasing the quantity and improving the quality of food, often with minimal or no additional inputs, will increase profits to poor producers, improve the availability and quality of food for poor consumers and contribute to economic growth;
- stabilizing food supply will provide sustainably improved nutrition and associated health benefits for poor consumers;
- generating employment through labour-based technologies will increase the incomes of poor labourers and contribute to economic growth;
- guaranteeing local product supply will increase the incomes of poor traders, transporters and processors and contribute to sustained economic growth;
- minimizing production risks from unpredictable and epidemic pests will stabilize production for poor producers (although farmers are not as risk-averse as they are sometimes presented to be — see

Chibnik)[51] and contribute to economic growth;
- minimizing health risks through reduced use of pesticides will contribute to improved health for poor producers, labourers and consumers;
- improving agroecosystem health (eg water quality) through reduced use of pesticides and improved fertilizer use efficiency will benefit all;
- decreasing unit production costs will increase profits for poor producers and facilitate use of appropriate levels of resources for additional food production, income generation and, potentially, cheaper food for poor consumers; and
- increased production per unit area will decrease cropland expansion into natural and marginal environments, reducing degradation of the environment and the natural resource base for the benefit of all.

Pest management — whether based on genetic, cultural, biological or chemical technologies, or their integration into an IPM strategy — has successfully contributed to increased production, increased profitability, decreased food prices, improved yield stability, reduced economic risks, increased employment and improved environmental conditions for the benefit of the poor. Selected contributions are highlighted below. Most relate to rice and wheat, for which considerable analysis has been published.

Improved genetic resistance

Modern plant breeding has put considerable effort into increasing the genetic resistance of major staple crops to important pests and diseases to reduce losses. It allows the combination of a vast range of useful characters in an infinite number of associations and then applies intense selection pressure to retain the best. It protects vulnerable farmers from the unpredictable effects of pests and associated losses.

Stem and leaf rusts have been the most intractable diseases of wheat since domestication.[52] In the nineteenth century, Indian farmers faced epidemics of devastating rusts at least once each decade.[53] Average annual losses due to rusts prior to the widespread adoption of improved, rust-resistant cultivars amounted to 10% of the value of the crop.[54] During the 1960s–80s, a major effort was made in developing countries to improve the resistances of staple food crops such as rice and wheat to important diseases and pests. Improved, semi-dwarf wheats were more resistant to leaf and stem rusts than landraces and early bred varieties,[55] although many of these were sources of the useful characters. Improved HY wheat varieties have resistances to rusts, leaf blotch, scab, bacterial leaf streak, barley yellow dwarf virus, tan spot, net blotch and karnal bunt,[56] while improved HY rice varieties have resistances to plant hoppers, stem borers, gall midge, blast, bacterial leaf blight, tungro virus and grassy stunt virus.[57]

By the early 1990s, HY rice varieties with multiple pest resistances had almost completely replaced the first HYVs such as IR8.[58] The yield-increasing effect of the second generation HYVs over the first generation was highly significant, both under irrigated conditions and during the dry season. The green revolution would not have been as revolutionary without the development and diffusion of second generation HYVs with multiple pest resistances. Similar conclusions have been drawn for wheat in Nepal.[59] Breeders of major food crops continue to build on established gains through effective productivity maintenance breeding.[60]

The widespread availability of pest-resistant HYVs of staple cereals has made a major contribution to increased productivity, increased yield stability and cheaper food, and has prevented further poverty.[61] For example, in India, yields of wheat and rice increased by 120% and 170% respectively; grain output increased twice as fast as population growth; year-to-year fluctuations in yield were reduced; prices of wheat and rice halved; and employment per ha increased by 30–50%.[62] In the late 1980s to early 1990s in northern Kanataka, the pigeon-pea granary of South Asia, 60% adoption of the wilt-resistant variety, *Maruti*, resulted in 50% higher yields, reduced production costs, and showed IRRs of 65%.[63] In Maharashtra, 70% of farmers who adopted improved disease-resistant groundnut varieties generated higher yields and greater profits.[64] In the Philippines, rice losses from insect pests have decreased from 23% to less than 10% due to the increasing use of pest-resistant varieties and improved IPM practices by farmers since the 1970s.[65]

Although fewer spectacular examples have been documented from Sub-Saharan Africa, modern plant breeding has not bypassed the continent. For example, Okashana 1, essentially developed through ICRISAT's breeding programme in India, has been rapidly adopted in Namibia to comprise 50% of the pearl millet area, increasing national production by 20%. There was a net improvement in the welfare of both producers and consumers.[66] Similarly, adoption of the sorghum S35 in Cameroon and Chad gave farmers a significant reduction in production costs, resulting in net benefits and profitability of £10 million and IRRs of 75–95%.[67] Although a relatively

Box 1

CPP projects developing and promoting improved disease, insect pest and parasitic weed-resistant varieties for use by poor farmers:

R6519: Management of rice tungro through the use of resistant varieties in Asia.
R6654/R6921/R7564: Integrated management of *Striga* in cereal systems in eastern and southern Africa, including the use of tolerant sorghum varieties.
R7445: Development of acceptable groundnut varieties with durable resistance to rosette disease in Uganda.
R7460: Development of improved tomato lines with resistance to ToLCV in India.
R6642/R7429: Promotion of the improved maize streak virus-tolerant variety, *Longe 1*, to resource-poor farmers in Uganda.
R7569: Promotion of acceptable and marketable disease-resistant bean varieties to resource-poor farmers in the Southern Highlands of Tanzania.

Figure 2. Development of farmer-acceptable groundnut varieties with resistance to rosette in Uganda.

Figure 3. Promotion of maize streak virus-tolerant Longe 1 maize variety in Uganda.

minor crop 100 years ago, maize now dominates the food economy in southern Africa, with over 20 million ha producing 26 million tonnes.[68] An estimated 40% of this area is sown to improved varieties (open-pollinated and hybrids) with resistances to important pests.[69] Also, since 1991 efforts to promote African cassava mosaic virus-resistant varieties in Uganda have resulted in almost 60% of the affected areas being replanted, with savings of £40 million.[70] Examples of current CPP projects developing and promoting improved, pest-resistant varieties for use by poor, small-scale farmers are given in Box 1 (see also Figures 2 and 3).

Reduced pesticide use

In rice in tropical Asia, a large number of pest outbreaks have been associated more with injudicious pesticide applications than with the breakdown of host plant resistance, high cropping intensity and/or high fertilizer use.[71] The best example is the emergence of the rice brown plant hopper (BPH). Prior to 1970, the BPH was a virtually unnoticed member of the fauna of tropical rice fields.[72] Its meteoric rise as one of the most important pests of rice in South-east Asia was strongly associated with substantial overuse of pesticides. During its heyday in the 1970s–80s, losses due to BPH amounted to £billions. Investments in crop protection research by the UK government successfully to manage BPH in the late 1980s and early 1990s (including biogeography and migration; ecology; development physiology; feeding behaviour and resistance mechanisms; modelling; and pest management) totalled £12 million.[73]

The impact of the BPH in Indonesia alone was profound. In the early to mid-1980s, Indonesia spent over £75 million per year in pesticide subsidies to control BPH.[74] In 1986, a presidential decree banned the use of 57 insecticides on rice and also removed pesticide subsidies.[75] This was an essential prerequisite for the success of the IPM programme implemented throughout Indonesia. Average pesticide applications per farm decreased from 4.0 to 0.8 between 1986 and 1991. The benefits of this programme to the poor can be expressed as: increased rice yields and profits; decreased rice prices for poor consumers; and a safer environment for all.[76] The return on investment in IPM training was 4.6–8.6:1.[77]

In Sri Lanka, the promotion of IPM in rice has resulted in a fivefold reduction in pesticide use amongst farmer beneficiaries. This was associated with mean yield increases of more than 11% and mean increases in net income of at least 44%.[78] An IPM programme for soya beans in Brazil from 1974–82 led to an 80–90% reduction in pesticide applications.[79] An IPM programme for cotton in Egypt resulted in a 70% reduction in pesticide applications and £35 million per year was saved from pesticide imports.[80] Adoption of IPM of *Spodoptera* in groundnut on the east coast of India substantially reduced pesticide use and increased poor farmers' profits.[81] A recent study in Kenya showed that farmers could save more than Ksh1000 per household per year through more rational use of pesticides on kale and cabbage. Box 2 gives examples of CPP projects that contribute to the reduced use of pesticides.

Figure 4. Development of SeNPV for control of army worm in Tanzania.

Pesticide use in developing countries is small in comparison with the rest of the world.[83] For example, the share of total pesticide use in rice in India and Bangladesh is only 7% (and 1% of global use). Total global rice pesticide use costs £2.5 billion. Unfortunately, however, a large proportion of the pesticides used in developing countries are highly hazardous Category I and II chemicals (including organochlorine, endosulphan, organophosphate, carbamate and pyrethroid-based chemicals), many of which have been banned from use in developed countries.[84] Moreover, it is predicted that the market for pesticides in developing countries will increase, both in total amount and share in the next decade,[85] particularly if there are no viable alternatives available. Indiscriminate use of hazardous pesticides may impair health due to direct exposure. Health problems may also be caused by indirect exposure due to contamination of ground and surface water through run-off, seepage and transmission of pesticide residues through the food chain. Additional problems include increased pest resistance to pesticides, which often leads to pest outbreaks and reduced populations of natural enemies, thereby reducing the effectiveness of IPM strategies[86] (see Box 2, R6734/6788). All these dangers will negatively affect the poor.

Widespread, poorly regulated and unsafe use of pesticides in one major rice growing area in the Philippines has been strongly linked to increased (27%) occupational poisoning of poor agricultural labourers between 1972 and 1984.[87] The results suggested that there could be a substantial underestimation of the number of deaths (10,000) attributed to accidental intoxication with insecticides worldwide. A study in Cochabamba, Bolivia, showed that 29% of agricultural labourers regularly involved in applying pesticides to horticultural crops showed symptoms of pesticide poisoning.[88] Similarly, in Santa Cruz, Bolivia, where 40% of pesticides used were highly toxic Category I, 64% of agricultural labourers involved in applying pesticides showed symptoms of poisoning.[89] This can also result in the reduced ability of poisoned labourers to work, earn income and support families.

The financial cost of pesticide poisoning, as well as environmental pollution, resulting from pesticide use is difficult to estimate, and as a consequence is rarely quantified. One study in Germany estimated that these 'additional costs to society' amounted to an additional 18% of the total cost of pesticides used.[90] This figure is likely to be higher for developing countries and for individual households affected by pesticide poisoning.

The adoption of IPM practices

Box 2

CPP projects that contribute to reduced use of pesticides:

R6764/R7430: Development of IPM strategies for vegetables based on more effective application of safer, selective pesticides that are less costly and have fewer health risks in Kenya and Zimbabwe.

R6616/R7403: Development of simple modifications to spray lances to improve targeting and reduce applications of pesticides in Kenya.

R7071: Development of IPM strategies for dry season vegetables in rice-based systems in West Bengal.

R7447: Development of IPM strategies for fruit and vegetable flies in Pakistan.

R6734/R6788: Wide-scale promotion of insecticide resistance management strategies for cotton bollworm in India.

Box 3

CPP projects developing pheromone technologies and insect pathogens (natural agents) for more environmentally sound pest management:

R6653: Use of *Metarhizium anisopliae* fungus for control of termites in maize in Uganda.
R6693: Promotion of pheromone technology for millet stem borer in West Africa.
R6746: Development of the virus SeNPV for control of army worm in Tanzania.
R7449: Development and promotion of a pheromone and the virus, PxGV, for diamond back moth in peri-urban brassica production systems in Kenya.
R7441: Development and promotion of pheromone technology for cowpea pod borer in West Africa.

based on improved resistances, use of biorationals (eg pheromone technologies, insect pathogens and botanicals) and crop management resulted in total insecticide use in rice, for example, falling by 10% between 1989 and 1993. In the Philippines, management through natural enemies combined with resistance in irrigated rice was consistently found to be the most profitable option for the poor farmer. It was even greater when the health costs of exposure to insecticides were explicitly accounted for, because the positive production benefits of applying insecticides are overwhelmed by the increased health costs.[91] Box 3 lists CPP projects developing biorational approaches to management of serious insect pests (see also Figure 4).

Herbicides, however, continue to have a significant impact on productivity in weed management.[92] It is believed that herbicides will continue to be the preferred practice in intensive cereal production systems, and will be used increasingly in developing countries in the foreseeable future. Herbicides are cost-effective relative to labour (wage rates for weeding surpass those of other management practices). There are also substantial human benefits (eg through reducing the drudgery of weeding — see Gressel).[93] Productivity benefits from herbicide use have been demonstrated even when health costs were explicitly accounted for.[94] The CPP has invested in projects to develop appropriate, cost-effective herbicide technologies for *Cyperus* in smallholder systems in West Africa; for weeds in maize/coffee systems in Kenya (R7405); and for weed management in direct-seeded rice in high-potential systems in India (R7337).

Biological control

The most dramatic example of the successful application of biological control as a pest management strategy is the control of the cassava mealy bug in Sub-Saharan Africa. Biocontrol of the mealy bug resulted in enormous savings of staple food across the cassava belt of Africa. Minimum expected benefits over 40 years are £6 billion from a total expenditure of £40 million, a cost–benefit ratio of 150:1.[95] Examples of CPP projects using augmentation of natural insect pathogens, both viruses and fungi, for management of serious pests are given in Box 3.

Natural enemies successfully control rice pests under irrigated conditions throughout tropical Asia, usually without the need to apply additional control practices.[96] These include parasitoids of eggs and nymphal stages of pests as well as predators of eggs, nymphs and adults, such as the mirid bugs and wolf spiders. This high level of natural control is attributed to the long association between the crop, its pests and co-evolved communities of beneficial species. Settle *et al*[97] showed that the ecology of the irrigated rice crop is the key factor. As the rice crop develops, detritus from previous crops in the flooded field allows the build-up of detritus feeders; these are then preyed upon by beneficial species, whose populations build up to a level that permits early and effective control of rice pests.[98] Reduced pesticide use has paved the way for innovative practices, such as rice–fish culture that increases available protein and income to poor households. Encouraging findings such as these should stimulate more studies in rice and other pro-poor cropping systems. Some examples of CPP projects studying and fostering natural enemies of serious insect pests are given in Box 4.

Box 4

CPP projects characterizing, understanding and fostering natural enemies for effective pest control:

R7267: Taxonomy and control of legume pod borers through their natural enemies in Sub-Saharan Africa and South Asia.
R7269: Pest and natural enemy dynamics in rainfed rice systems in Bangladesh.
R7570: Functional crop associated biodiversity in rice-based systems in West Africa and South Asia.

Greater yield stability

Sound pest management practices can contribute to more stable, less risk-prone crop production that benefits the poor and is an essential part of sustainable livelihoods. The coefficient of variation for global rice production and global rice yields has been declining since 1960.[99] In six out of eight countries surveyed in South and South-east Asia (India, Thailand, Bangladesh, Pakistan, Vietnam and the Philippines), this was indeed clear. Yields have become more stable, partly due to improved pest management practices. The higher and more stable yield potential and profitability of green revolution wheat and rice varieties permits farmers to invest in inputs for producing even more food and income[100] for the benefit of both the producer and the consumer. For wheat, much of this stability is related to the widespread use of varieties with durable resistances to stem and leaf rusts.[101] For rice, multiple resistance to major pests and diseases as well as efficient IPM practices have made a similar contribution to yield stability.[102]

Lower food prices

There are many cases in which prices of wheat and rice have decreased due to agricultural research, including crop protection technologies, and as a result, have greatly benefited poor consumers.[103] Over the past 20 years agricultural research has contributed to a dramatic fall in the World Food Price Index (see Conway,[104] Figure 1.4). Without the impact of the green revolution, food prices would have been higher, employment growth slower, and poverty more widespread[105] — exacerbating the threat to natural biodiversity (see below). The Great Bengal rice famine illustrates the critical importance of food prices to the poor. In 1942–43, cyclones, floods and an epidemic of brown spot reduced the Bengal rice crop.[106] Inflationary forces associated with a war economy led to a quintupling in the price of rice between September 1942 and August 1943.[107] The inability to import rice from Japanese-controlled Burma, coupled with uneven expansion in incomes and purchasing power in the fight for command over food, led to famine, starvation and death. Between 1.5 and 3 million people died. Poverty increased sharply during this period. The landless agricultural labourers and their families were worst affected: over 40% perished because of their inability to establish an entitlement to food due to the quintupling of rice prices.[108]

Between 1982 and 1995, world staple cereal prices dropped by 28% for wheat, 42% for rice and 43% for maize.[109] World prices for major cereals are the lowest they have been for the last century and are projected to decline in the future, but at slower rates than during the past two decades. Lower staple food prices due to improved agricultural technologies, including crop protection technologies, will continue to benefit poor consumers, especially the growing urban poor.[110]

Enhanced natural resource management and biodiversity conservation

The contribution of agricultural research, including the sound use of crop protection technologies, to reducing the pressure to cultivate biologically diverse, fragile, marginal or forested areas, and to protecting the natural resource base, has not been widely recognized.[111] The diffusion of improved rice and wheat technologies, including host plant resistance and IPM, has resulted in sustained economic growth in Bangladesh; higher incomes in India; improvements in income distribution in Pakistan; and the saving of many millions of hectares from the plough and axe. Without improved agricultural technologies, another 350 million ha would have had to be cropped to produce enough food for the world's population — an area about the size of India[112] — which would have resulted in an environmental disaster of immense proportions.[113] In India alone, another 40 million ha would have been needed to meet the demand for rice and wheat.[114] In China too, the cultivated cereal area would have had to be increased threefold.[115] Farming would have expanded on to highly erosion-prone soils and forests, other natural vegetation would have been destroyed, and with it much biodiversity. All crop protection technologies that contribute to increased crop yields from the same unit area of land potentially contribute to reduced expansion of farming into fragile and natural areas.

Specialization and intensification in agriculture on high quality land could be the best hope for maintaining increased productivity and reducing damage to marginal ecosystems.[116] The hallmark of twentieth century agriculture has been the widespread adoption — by both poor and rich alike — of yield-increasing, land-saving technologies, which have permitted agricultural research to keep pace with rapid population growth. For example, the cropping intensity in Bangladesh is over 180%[117] and Nigeria, Kenya and Ethiopia now surpass major Asian countries in intensity of land use.[118] In addition, intensification has taken pressure off the useful biodiversity of natural vegetation, which greatly enhances livelihood options for rural people (eg gathering fuel; collecting wild foods such as honey and herbs to improve diet; and harvesting natural products for crafts such as basket making, for income generation).[119] In addition, the development of crop and land management strategies that more wisely manage resources in fragile areas will reduce damage to marginal ecosystems. Box 5 provides examples of CPP projects that will contribute to enhanced natural resource management and conservation.

Box 5
CPP projects contributing to enhanced natural resource management and conservation:
R7325: Integrated weed management strategies to reduce soil erosion risks on fragile Andean hillsides in Bolivia.
R7491: Integrated management of *Nacobbus* nematodes and weeds on hillsides in Bolivia.
R7579: Strategies for forage production and erosion control as a complement to hillside weed management.
R7569: Promotion of farmer- and market-acceptable, disease-resistant beans in the Southern Highlands of Tanzania.

Rural employment opportunities

Over the past 10–15 years, the poor in developing countries have become increasingly dependent on employment to acquire food.[120] Improved agricultural technologies raised employment by 30–50% in the 1970s. Today such technologies raise employment by only 10–30% as small, poor farmers adopt labour-saving technologies to maintain their profit margins. *Can agricultural technologies of the future continue to raise and stabilize yields and provide cheaper food, as well as developing labour-intensive technologies that are acceptable to small, poor farmers?* Balancing the needs of poor producers with those of the landless labourers and the urban poor may at times require difficult choices[121] for crop protection research.

Current trends in weed management reflect this dilemma. For many crops, especially rainfed cereals, cotton and grain legumes, a considerable amount of time is spent in weeding: this constitutes sheer, routine drudgery for the disadvantaged parts of the labour force such as women and children. Such time is often better spent in livelihood-generating activities such as growing cash crops, food processing, etc for women and schooling for children. Labour for weeding can also be the biggest input expense for the poor producer. As the cost of labour increases, poor producers move to labour-saving technologies such as weed-competitive varieties, mechanization and herbicides. As a result, their requirements for labour decrease. From 1989–93, herbicide use in cereal crops grew at 4% per year[122] and it is likely that herbicides will continue to be used in such cropping systems in developing countries in the future because they are cost-effective relative to labour.[123]

The development of weed-competitive rice is receiving much research attention in West Africa,[124] partly supported by DFID (R7022). It is the poorest farmers in marginal conditions such as the upland rice ecology in this region who face both severe problems with weeds and seasonal labour shortages. Labour-saving weed management technologies such as weed-competitive varieties and herbicides will help to keep them farming profitably and produce rice for both the rural and urban poor. If widely adopted in rice systems in South Asia, especially where labour supply may be less constrained, such varieties could decrease employment opportunities for poor labourers in rural areas. There is also clearly a need to look for labour-intensive and profit-generating technologies such as pest-resistant hybrid rice seed production, in which the extra labour costs are compensated by higher productivity and higher value of the product.[125]

Clearly the answers to the rural employment dilemma are not only farm-based. Countries currently making progress in stimulating rural economies have created off-farm earning.[126] There is also a need to develop policies and incentives to promote local industries such as food processing, which will generate additional off-farm employment opportunities for landless labourers for the good of the whole rural economy.

Approach of the Crop Protection Programme to meeting DFID's agenda

The CPP focuses its resources through projects to manage major pests of priority staple food crops (cereals and root crops), nutritionally valuable crops (vegetables, pulses) and income-generating cash crops (cotton, coffee, fodder, feed grain, etc) crucial to the welfare of the poor, across six production systems principally in priority developing countries in Sub-Saharan Africa and South Asia. Such projects involve diagnosis and characterization of economically important pests of priority crops; development of improved pest management technologies for priority crops in priority countries; and the promotion of cost-effective, socially and environmentally acceptable IPM technologies. The strategic focus is increasing crop production through improved pest management, resulting in more and higher quality food that will contribute to household food security and reduce malnutrition, generate income and employment, and improve livelihoods — all of which contribute to poverty elimination.

The Sustainable Livelihoods Framework has been adopted by DFID as a way of analysing poverty issues and formulating more effective development strategies to alleviate poverty.[127] Analysis of how pest management strategies can enhance the asset status for particular groups of people provides entry points to the framework for the Crop Protection Programme. The framework is also helping the Crop Protection Programme to assess the impact of new crop protection technologies and their potential benefits for the poor, and to identify areas that need to be strengthened to facilitate uptake of sustainable pest management practices.[128]

Agricultural productivity increases needed to lift the poor out of food insecurity and sustain livelihoods without doing irreparable damage to the environment will be possible only if the appropriate government policies are established. Sustainable agriculture and rural development must be integrated into agricultural policy.[129] Policies need to recognize the importance of agricultural research, the need to link this to extension and development programmes, and *most importantly*, the need to establish feedback mechanisms between research and extension.

Scientists characteristically draw back from policy issues, although there are important areas in which a sound knowledge of crop protection technologies is essential to address concerns over agricultural practices. For example, pesticides remain a concern in agricultural policy. The right policies on pesticides could accelerate crop productivity and contribute to environmental sustainability. The wrong policies could allow farmers access to subsidized damaging Category 1 pesticides, resulting in environmental degradation and ill health. The development of regulatory frameworks and registration systems for biopesticides will provide farmers with environmentally benign pest management alternatives. Government policies to support improved seed distribution systems will facilitate farmer access to pest-resistant varieties. Crop protection scientists have a responsibility to contribute to the policy debate on such issues. Opportunities are being sought through CPP projects to develop and present advice on crop protection issues, eg through international and regional IPM fora to inform policy makers.

Much of CPP's contribution to the management of serious pests of staple food and cash crops over the past five years, and as a consequence to poverty elimination and reduced natural resource degradation, has been possible due to a unique suite of partnerships. The CPP funds demand-led projects in partnership with National Agricultural Research Systems (NARS), International Agricultural Research Centres (IARCs), non-governmental organizations (NGOs), other DFID and non-DFID programmes and development agencies, the private sector and farmers. Well managed partnerships reduce transactional costs, optimize risk allocation, augment resources and competencies, and increase the potential scale of impact. Long-term partnerships based on trust are an important foundation for research and development and an essential prerequisite for developing functional uptake pathways for the successful promotion and adoption of research outputs in developing countries. New partnerships will also be needed to ensure that the policy and institutional frameworks for capitalizing on the contribution of improved crop protection technologies to poverty elimination and sustainable livelihoods are in place.

Targeting crop protection research outputs at the poor

The CPP has a strong geographic focus on the poor, with approximately 60% and 30% of projects and programme budgets respectively targeted at Sub-Saharan Africa and South Asia. These regions are the ‘hot spots’ of poverty and malnutrition with almost 70% of the world’s most food-insecure — more than 800 million people (43% in South Asia; 24% in Sub-Saharan Africa)[130] — who do not have enough dietary energy and protein.[131] In addition, of the estimated 160 million malnourished children globally, approximately 100 million live in Asia and 40 million in Sub-Saharan Africa. Bolivia, the only other country outside these two regions where the CPP supports several projects, is considered to be one of the poorest countries in Latin America. The focus here is on the fragile, erosion-prone hillsides, which are home to many resource-poor people.

The CPP also targets poverty elimination through pest management across production systems (eg Semi-Arid, Peri-Urban, High Potential, etc) which may have different levels of poverty and different proportions of categories of the poor: producers, landless rural labourers, and rural and urban consumers. For example, the Semi-Arid Production System is home to about one billion people, of whom approximately 350 million (44% of the global total) are poor, food-insecure and mostly involved in agriculture. Almost 25% of the CPP budget presently supports projects developing crop protection technologies for damaging pests (including migrant pests) of staple cereals and associated legumes as well as cotton in this production system. Growing urbanization in developing countries may change the CPP’s focus towards the High Potential and Peri-Urban Production Systems due to the need to manage serious pests of staple food (eg rice, maize) and nutritional crops (eg vegetables) to meet the needs of increasing numbers of urban poor. Care is taken to balance the programme investment in pest management projects that contribute to increased yields with fewer inputs for poor producers, and reduced food prices for poor consumers.

The CPP gives priority to the management of pests of staple food crops. In South Asia, the priority crop is rice, the most important food crop of the poor in this region. The programme maintains a focus on irrigated rice in the High Potential Production System due to its importance in the diets of the urban poor. An evolving focus is developing on rainfed rice in the Land–Water Interface Production System where pests are generally more numerous, serious and difficult to manage. Here the balance benefits small producers in South Asia and West Africa (rice thematic clusters — Table 2). In Sub-Saharan Africa, the CPP gives priority to a range of staple food crops including maize, banana, sorghum, millets, rice, cassava, yam and sweet potato (maize, banana, semi-arid cereals, root-crops thematic clusters — Table 2). Some of these crops, eg sorghum and millets, grow in marginal semi-arid environments where sound pest management technologies will principally benefit poor producers; others, eg sweet potato and cassava, are both staple and food security crops. Increased production will benefit both poor producers and consumers. The world demand for cereals and root and tuber crops will grow by at least 40% during the next 20 years.[132] Developing countries will account for 85% of this increased demand as the poor are highly dependent on such crops.[133] If management of serious pests results in increased rice production in South Asia and increased cereal and root crop production in Sub-Saharan Africa, the poor are likely to benefit more than other strata of society.

Management of pests in cash crops such as coffee, cocoa, cotton, coconut and oil palm in the Forest Agriculture Interface, Semi-Arid and Land–Water Interface Production Systems is also important as such crops are key generators of employment income for poor landless labourers and foreign exchange for developing country economies. Growing cash crops increases a country’s overall earning power and strengthens the economy. Economic growth in rural areas is a very effective instrument for poverty elimination in countries where the majority of poor are rural — as in South Asia and Sub-Saharan Africa. Care, however, will be taken to ensure that this does not weaken national food crop production (through cheap food imports) and lead to a decline in the national food production capacity and the rural economy. To avoid this, the CPP targets smallholder cash cropping systems and not large plantation cropping systems. The programme has thematic clusters of projects on pest management in cotton, coffee (Table 2), cocoa and coconut.

Management of pests in nutritionally valuable crops is also targeted because of their importance in the nutrition of poor consumers and as additional sources of income for poor producers. In Peri-Urban Production Systems in developing countries, the most important commodity cultivated by small producers consists of vegetables for sale in urban markets — vegetable thematic clusters (Table 2). Overuse of pesticides is of growing concern as urban consumers, even in developing countries, demand blemish-free produce. The development of effective, environmentally sound management technologies such as host plant resistance, enhanced biocontrol, use of biorationals (pheromones, insect pathogens and botanicals) and cultural control will greatly reduce the use of pesticides in such systems, resulting in safer, higher quality produce for consumers and a safer working environment for labourers and producers.

Table 2. Contributions of selected CPP thematic project clusters to poverty elimination.

Thematic cluster	Pests	Management strategy	Poverty elimination targets
Rice in South Asia R6519, R6643, R6739, R7377, R7296, R7471) Rice in Sub-Saharan Africa (R6763, 6658, 6738, R7345, R7552)	Tungro, sheath blight, yellow stem borer, weeds Weeds, RYMV, nematodes, blast	Resistance, cultural control, IPM	Major food source for the world's poor: decreased losses; increased production, reduced inputs, increased profits for producers; cheaper rice for consumers; safer working environment for labourers.
Maize in eastern and southern Africa (R6642, R6921, R6654, R6582, R6653, R7405, R7429)	Streak, *Striga*, ear rots, grey spot; termites, weeds	Resistance, cultural control, IPM	Major food source for the African poor: decreased losses, stabilized yields, increased availability, increased profits for producers; cheaper maize for consumers; increased employment opportunities for labourers.
Root & tuber crops in East and West Africa (R6614, R7563, R6691, R6694, R7563, R7492, R7565)	Cassava mosaic, brown streak, yam diseases and nematodes, sweet potato viruses	Resistance, biocontrol, IPM	Major food security crops: decreased losses, increased food availability, increased profits for producers; cheaper food for consumers.
Banana in East Africa (R6692, R6582, R6580, R6579, R7478, R7529, R7567)	Sigatoka leaf spot, Fusarium wilt, nematodes, virus, weevil	Resistance, cultural and biocontrol, IPM	Major food source for the East African poor: decreased losses, reduced costs of production for producers; increased food availability for consumers; increased employment opportunities.
Cotton in India (R5745, 6734, 6760, 7004)	Bollworm	Resistance management, biocontrol, IPM	Major base of the rural economy and export crop: reduced costs and increased profits for producers; increased employment opportunities for labourers; safer environment for all.
Vegetables in Sub-Saharan Africa (R6146, 6799, 6615, 6616, 6629, 6620, 6764, 6657, R7403, R7449, R7472)	Diamond-back moth, fungal diseases, nematodes, viruses, weeds	IPM, biocontrol, biorationals, resistance, cultural control	Major base of the peri-urban economy: decreased losses, secure and profitable livelihoods for producers; safer food for consumers; safer working environment for labourers.
Coffee in eastern and southern Africa (R6782, R6807)	Diseases, insect pests	IPM, biocontrol	Major base of the rural economy and export crop: decreased losses, increased production, higher quality, lower production costs, reduced health risks for producers and labourers.
Semi-arid cereals and associated legumes in East Africa (R6654, R6921, R7401, R7445, R7518, R7572)	Diseases, insect pests, weeds	Resistance, IPM	Major food and cash crops in SAT: decreased losses, increased production, increased food availability for consumers; women will benefit most.

In Semi-Arid, Hillside and Forest-Agriculture Production Systems, the programme is expanding its investment in projects focused on the management of serious pests of pulses or food legumes including groundnut, pigeon pea, common bean, chickpea and cowpea in Sub-Saharan Africa (Uganda, Kenya, Tanzania, Ghana, Nigeria) and South Asia (India, Nepal) (includes the hillside pulse clusters and semi-arid cereals and associated pulse clusters, Table 2). An expanded focus on food legumes will reduce food insecurity and enhance the nutrition of the poor (especially children) and provide income for women who are the principal cultivators of food legumes, especially in Sub-Saharan Africa. Legumes also fix soil nitrogen of benefit to subsequent crops and to soil fertility in general, which can reduce the need for chemical fertiliszers. Their haulms also provide high quality fodder to livestock, an integral part of the livelihood strategy of many poor people.

A demand-driven livestock revolution is gathering momentum in the developing world. Demand for meat and animal products such as milk and eggs will double by 2020.[134] This will substantially increase the demand for good quality fodder and feed grain. Livestock are the walking wealth of many poor farmers in Sub-Saharan Africa and South Asia. They are an integral part of all production systems targeted by the programme. Thus a systems approach to managing biotic constraints that may affect the production and nutritive value of important fodder sources for livestock is being developed by the programme. A new project was initiated in the reporting year on assessing the effects of diseases on the quality and nutritive value of sorghum and groundnut crop residues destined for intensive dairy systems in Peri-Urban/Semi-Arid areas of the Deccan Plateau, India (R7346). A further project is being planned on managing diseases of maize/Napier grass zero-grazing cattle systems in Peri-Urban/High Potential areas of central Kenya. A short project analysed the technical and institutional options for management of sorghum grain mould in India, with a focus on intensive poultry production in Peri-Urban/Semi-Arid areas (R7506).

Targeting crop protection research at the poor could be improved by poverty mapping. Bigman and Loevinsohn[135] emphasize that both mapping the incidence of poverty and the incidence of benefits from agricultural research and development programmes in the same geographical areas and farming systems can add significantly to the ability of research efforts to benefit the poor. For example, a recent study in Matabeleland, Zimbabwe, showed that the poorest farmers were reluctant to use chemical inputs as they were expensive and perceived to be risky, although on-farm trials had indicated the contrary for small, strategic applications. Experiments can now be targeted to demonstrate the benefits of such applications to the poorest farmers.[136] The programme is presently exploring possible collaborative partnerships to map poverty in selected priority geographical target areas and production systems to improve the targeting of technologies at the poor and to refine its poverty focus.

Future needs

Improved pest management is an essential part of a holistic approach to agricultural research and development in South Asia and Sub-Saharan Africa where almost 70% of the global poor reside. The past contribution of crop protection research and development to poverty elimination, enhanced livelihood security and reduced environmental degradation has been summarized in this article. Excellent progress has already been made during the first five years of the CPP in the development, application and promotion of a broad range of pest management technologies, which farmers have already adopted and continue to adopt, especially in South Asia and Sub-Saharan Africa, home to most of the world's poorest people. The contribution of these technologies to poverty elimination, enhanced livelihood security and reduced environmental degradation is now being acknowledged.

At the same time it must be acknowledged that crop protection research is a somewhat blunt instrument for tackling poverty elimination. Benefits such as reduced crop losses, increased and stabilized yields, increased farm income, greater employment opportunities, lower food prices and reduced economic risks do not always materialize for the poor as a result of adopting improved crop protection practices due to innumerable external factors including climatic, social and political factors. These factors work in a myriad of complex and often conflicting ways, and the outcomes are difficult to predict *a priori*.[137]

Today's approach to poverty issues in agricultural research acknowledges that the global agenda has changed substantially since the period of the green revolution, when increased aggregate food supply *alone* was considered the principal way of reducing hunger and poverty. New policy agendas are asking agricultural research to deal with phenomena that are often beyond the capability of research programmes. The approach of the CPP is firstly to focus on what it can do best to contribute to poverty elimination: developing pest management strategies that contribute to reducing losses; increasing and stabilizing yields; reducing pesticide use; and reducing economic risks. Second, to further its objectives, the CPP is working more closely with development partners and increasingly with decision and policy makers. The closer integration of the different contributions throughout the agricultural research and development community, as well as from other sectors, is key to ensuring that CPP research outputs lead to poverty elimination.

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Notes and references

[1]DFID, *The White Paper: Eliminating World Poverty: A Challenge for the 21st Century*, DFID, London, 1997; DFID, *Strategies for Achieving the International Development Targets: Environmental Sustainability and Eliminating Poverty*, DFID, London, 2000.

[2]TAC, *Charting the CGIAR's Future — A New Vision for 2010*, TAC, Rome, May 2000.

[3]The term 'pest' is used *sensu lato* throughout the article. It refers to the complex of insect, nematode and vertebrate pests; fungal, bacterial, viral and phytoplasma pathogens; and weeds that affect crops. The term is qualified when it is used to specify a particular group of pests.

[4]UNDP, 'Poverty in the human development perspective: concept and measurement', in *UNDP Human Development Report*, Oxford University Press, Oxford, 1997, pp 15–23.

[5]D. Carney, *Sustainable Rural Livelihoods — What Contribution Can We Make?* DFID, London, 1998.

[6]A. Cox, J. Farrington and J. Gilling, 'Developing a framework to assess the poverty impact of NR Research', Final Draft to Steering Group, ODI/OPM, London, 1998.

[7]M. Lipton and R. Longhurst, *New Seeds and Poor People*, Unwin Hyman, London, 1989; M. Lipton and M. Ravallion, 'Poverty and policy', in J. Behrman and T.N. Srinivasan, eds, *Handbook of Development Economics*, Vol III, Elsevier Science, Oxford, 1995, pp 2552–2657.

[8]B. Baulch, 'Neglected trade-offs in poverty measurement', *IDS Bulletin*, Vol 27, 1996, pp 36–55; UNDP, *Poverty Eradication: A Policy Framework for Country Strategies*, UNDP, 1998.

[9]UNDP, *op cit*, Ref 8.

[10]P.B.K. Hazell, 'Agricultural growth, poverty alleviation and environmental sustainability: having it all', *2020 Vision Briefing*, IFPRI, Washington, DC, March 1999a.

[11]Carney, *op cit*, Ref 5.

[12]Lipton and Longhurst, *op cit*, Ref 7.

[13]Lipton and Longhurst, *op cit*, Ref 7.

[14]P. Pinstrup-Andersen, R. Pandya-Lorch and M.W. Rosengrant, 'The world food situation: recent developments and emerging issues and long-term prospects', *2020 Vision Food Policy Report*, IFPRI, Washington, DC, 1997.

[15] P. Pinstrup-Andersen, R. Pandya-Lorch and M.W. Rosengrant, 'World food prospects: critical issues for the early 21st century', *2020 Vision Food Policy Report*, IFPRI, Washington, DC, 1999.

[16]IITA, 'Towards sustainable development in Africa', *Medium Term Plan 1999–2001*, Ibadan, Nigeria, 1998; WARDA, *Medium Term Plan, 2000–2002*, WARDA, Buoake, Cote d'Ivoire, 1998.

[17]L. Haddad, M. Ruel and J. Garrett, 'Are urban poverty and undernutrition growing? Some newly assembled evidence', *FCND Discussion Paper No. 63*, IFPRI, Washington, DC, 1999.

[18]Lipton and Longhurst, *op cit*, Ref 7.

[19]S.R. Osmani, 'Did the Green Revolution hurt the poor? A reexamination of the early critique', in P.L. Pingali and M. Hossain, eds, *Proceedings of the International Conference on the Impact of Rice Research*, TDRI, Bangkok, and IRRI, Manila, 1998, pp 193–212.

[20]IRRI, *Partners — Making a Difference*, IRRI, Manila, 1997a.

[21]P.B.K. Hazell, 'The impact of agricultural research on the poor', paper presented at the CIAT Workshop on the Impact of Agricultural Research on Poverty Reduction, San José, Costa Rica, September 1999.

[22]Pinstrup-Andersen *et al*, *op cit*, Ref 14.

[23]M. Hossain, 'Rice research, technological progress, and the impact of rice research on the rural economy: the Bangladesh case', in P.L. Pingali and M. Hossain, eds, *Impact of Rice Research, Proceedings of the International Conference on the Impact of Rice Research*, TDRI, Bangkok, and IRRI, Manila, 1998, pp 311–342; M. Hossain and Q. Shahabuddin, 'Sustainable agricultural development in Bangladesh: challenges and issues', in S.I. Bhuiyan and A.N.M.R. Karim, eds, *Increasing Rice Production in Bangladesh: Challenges and Strategies*, IRRI, Manila, and BRRI, Dhaka, 1999, pp 53–63.

[24]Osmani, *op cit*, Ref 19.

[25]S. Sen, *Reaping the Green Revolution: Food and Jobs for all*, Tata McGraw-Hill, New Delhi, 1975.

[26]R. Tripp, 'Biodiversity and modern crop varieties: sharpening the debate', *Agriculture and Human Values*, Vol 13, 1996, pp 48–63.

[27]S. Fan, P. Hazell, and S. Thorat, 'Linkages between government spending, growth and poverty in rural India', *IFPRI Research Report*, No 110, IFPRI, Washington, DC, 1999.

[28]*Ibid.*

[29]Lipton and Longhurst, *op cit*, Ref 7; G. Conway, *The Doubly Green Revolution: Food for All in the 21st Century*, Penguin, London, 1997; L.T. Evans, *Feeding the Ten Billion: Plants and Population Growth*, Cambridge University Press, Cambridge, 1998.

[30]Lipton and Longhurst, *op cit*, Ref 7.

[31]IFPRI, 'News and views', *2020 Vision*, September, IFPRI, Washington, DC, 1999.

[32]C.E. Large, *The Advance of the Fungi*, Jonathan Cape, London, 1940; G.L. Carefoot and E.R. Sprott, *Famine on the Wind*, Angus and Robertson, London, 1969.

[33]Carefoot and Sprott, *op cit*, Ref 32.

[34]Large, *op cit*, Ref 32; S. Safeeula, 'Genetic vulnerability: the basis of epidemics in India', *Annals of the New York Academy of Sciences*, Vol 287, 1977, pp 72–85.

[35]A. Padmanabhan, 'The great Bengal rice famine', *Annual Review of Phytopathology*, Vol 11, 1973, pp 11–26.

[36]R.A. Naidu, H. Bottenberg, P. Subrahmanyam, F.M. Kimmins, D.J. Robinson and J.M. Thresh, 'Epidemiology of groundnut rosette disease: current status and future research needs', *Annals of Applied Biology*, Vol 132, 1998, pp 525–548.

[37]G.W. Otim-Nape, A. Bua, J.M. Thresh, Y. Baguma, S. Ogwal, G.N. Semakula, B. Byabakama and A. Martin, *Cassava Mosaic Disease in Uganda*, The University of Greenwich, London, 1997.

[38]R. Bandyopadhyay, D.E. Frederickson, N.W. Mclaren, G.N. Odvody and M.J. Ryley, 'Ergot, a new disease threat to sorghum in the Americas and Australia', *Plant Disease*, Vol 82, 1998, pp 356–367.

[39]F. Maxwell and P.J. Jennings, *Breeding for Insect Resistance in Crops*, Macmillian, London, 1975.

[40]P.L. Pingali and R.V. Gerpachio, 'Living with reduced pesticide use in tropical rice', *Food Policy*, Vol 22, 1997, pp 107–118.

[41]H.R. Herren and P. Neuenschwander, 'Biological control of cassava pests in Africa', *Annual Review of Entomology*, Vol 36, 1991, pp 257–283; Otim-Nape *et al*, *op cit*, Ref 37.

[42]E.C. Oereke, H.W. Dehne, F. Schonbeck and A. Weber, *Crop Production and Crop Protection: Estimated Losses in Major Food and Cash Crops*, Elsevier, London, 1994.

[43]P.J. Terry, 'The use of herbicides in the agriculture of developing countries', *Proceedings of Second International Weed Control Congress*, Copenhagen, 1996, pp 601–609.

[44]R.J. Hillocks, J.W.M. Logan, C.R. Riches, A. Russell-Smith and L.J. Shaxson, 'Soil pests in traditional farming systems in Sub-Saharan Africa — a review. Part 1. Problems', *International Journal of Pest Management*, Vol 42, 1996, pp 241–251.

[45]T. Gressel, 'Plant biotechnology can quickly offer solutions to hunger in Africa', *The Scientist*, Vol 19, 1996, p 10.

[46]C.R. Riches, S.J. Twomlow and H. Dhliwayo, 'Low-input weed management and conservation tillage in semi-arid Zimbabwe', *Experimental Agriculture*, Vol 33, 1997, pp 173–187.

[47]Lipton and Longhurst, *op cit*, Ref 7.

[48]H. Warburton and A.M. Martin, 'Pest management and poor people's livelihoods', in *1999 BCPC Symposium Proceedings No. 73: International Crop Protection: Achievements and Ambitions*, BCPC, Farnham, 1999, pp 33–55.

[49]Lipton and Longhurst, *op cit*, Ref 7; IFPRI, *op cit*, Ref 31.

[50]H.D. Thurston, *Sustainable Practices for Pest Management in Traditional Farming Systems*, Westview Press, Boulder, CO, 1992.

[51]M. Chibnik, 'Small farmer risk aversion: peasant reality or policymakers' rationalization', *Culture and Agriculture*, Vol 10, 1981, pp 1–5.

[52]P.W. Heisey, M. Smale, D. Byerlee and E. Souza, 'Wheat rusts and the costs of genetic diversity in the Punjab of Pakistan', *American Journal of Agricultural Economics*, Vol 79, 1997, pp 726–737.

[53]Safeeula, *op cit*, Ref 34.

[54]S. Nagarajan and L.M. Joshi, 'An historical account of the wheat rust epidemics in India and their significance', *Cereal Rusts Bulletin*, Vol 3, 1975, pp 29–33.

[55]S. Rajaram, R.P. Singh and E. Torres, 'Current CIMMYT approaches in breeding wheat for rust resistance', in N.W. Simmonds and S. Rajaram, eds, *Breeding Strategies for Rusts of Wheat*, CIMMYT, Mexico, 1988, pp 101–118; Heisey *et al*, *op cit*, Ref 52.

[56]Heisey *et al*, *op cit*, Ref 52.

[57]IRRI, *Medium Term Plan. IRRI, 1998–2002*, Manila, 1997b.

[58]K. Otsuka, F. Gascon and S. Asano, 'Second-generation MVs and the evolution of the Green Revolution: the case of Central Luzon, 1966–1990', *Agricultural Economics*, Vol 10, 1994, pp 283–295.

[59]M.L. Morris, H.J. Dubin and T. Pokhrel, 'Returns to wheat breeding research in Nepal', *Agricultural Economics*, Vol 10, 1994, pp 269–282.

[60]M. Smale, R.P. Singh, K. Sayre, P. Pingali, S. Rajaram and H.J. Dubin, 'Estimating the economic impact of breeding nonspecific resistance to leaf rust in modern bred varieties', *Plant Disease*, Vol 82, 1998, pp 1055–1061.

[61]Lipton and Longhurst, *op cit*, Ref 7; Tripp, *op cit*, Ref 26.

[62]CIMMYT, *Annual Report*, CIMMYT, Mexico, 1995; L. Harrington, 'Diversity by design', *CGIAR News*, Vol 4, 1997, pp 5–8; D.J. Greenland, *The Sustainability of Rice Farming*, CAB International, Wallingford, and IRRI, 1997; P.L. Pingali and M. Hossain, *Impact of Rice Research. Proceedings of the International Conference on the Impact of Rice Research*, 3–5 June, Bangkok, TDRI, Bangkok, IRRI, Manila, 1998; M. Smale, J. Hartell, P.W. Heisey and B. Senauer, 'The contribution of genetic resources and diversity to wheat production in the Punjab of Pakistan', *American Journal of Agricultural Economics*, Vol 80, 1998, pp 482–493.

[63]M.C. Bantilan and N.K. Joshi, 'Returns to research and diffusion: investments in wilt resistance in pigeon pea', *Impact Series*, No 1, ICRISAT, India, 1996.

[64]ICRISAT, 'A triple alliance towards prosperity', *Food from Thought*, No 6, ICRISAT, India, 1997.

[65]Pingali and Gerpachio, *op cit*, Ref 40; A.C. Rola and P.L. Pingali, *Pesticides, Rice Productivity and Farmers Health: an Economic Assessment*, World Resources Institute, and IRRI, Manila, 1993.

[66]D.D. Rohrbach, W.R. Lechner, S.A. Ipinge and E.S. Monyo, 'The impact from investments in crop breeding: the case of Okashana 1 in Namibia', *Impact Series*, No 4, ICRISAT, India, 1999.

[67]A.M. Yapi, S.K. Debrah, G. Dehala and C. Njomaha, 'Impact of germplasm research spillovers: the case of sorghum variety S35 in Cameroon and Chad', *Impact Series*, No 3, ICRISAT, India, 1999; A.M. Yapi, G. Dehala, K. Ngawara and A. Issaka, 'Assessment of the economic impact of sorghum variety S35 in Chad', *Impact Series*, No 6, ICRISAT, India, 1999.

[68]D. Byerlee and C.K. Eicher, *Africa's Emerging Maize Revolution*, Lynne Reinner Publishers, London, 1997.

[69]IITA, *op cit*, Ref 16; CIMMYT, *People and Partnerships. Medium Term Plan 1999–2001*, CIMMYT, Mexico, 1998.

[70]Otim-Nape *et al*, *op cit*, Ref 37.

[71]P.E. Kenmore, F.O. Cariño, C.A. Perez, V.A. Dyck and A.P. Gutierrez, 'Population regulation of the rice brown planthopper within rice fields in the Philippines', *Philippine Journal of Plant Protection in the Tropics*, Vol 1, 1984, pp 19–37; R.C. Joshi, B.M. Shepherd, P.E. Kenmore and R. Lydia, 'Insecticide induced resurgence of the brown planthopper, BPH, on IR62', *International Rice Research Newsletter*, Vol 17, 1992, pp 9–10; K.D. Schoenly, J.E. Cohen, K.L. Heong, G. Arida, A.T. Barrion and J.A. Litsinger, 'Quantifying the impact of insecticides on food web structure of rice-arthropod populations in Philippine farmers' irrigated fields: a case study', in G. Polis and K. Winemiller, eds, *Food Webs: Integration of Patterns and Dynamics*, Chapman Hall, New York, 1996, pp 343–351.

[72]T.J. Perfect, 'Brown planthopper: threat to the Green Revolution', inaugural professorial lecture, University of Greenwich and the Natural Resources Institute, Chatham Maritime, 27 May 1998.

[73]*Ibid.*

[74]Perfect, *op cit*, Ref 72.

[75]M. Thomas and J. Waage, *Integration of Biological Control and Host Plant Resistance Breeding: Scientific and Literature Review*, CTA publication, Wageningen, 1996.

[76]*Ibid.*

[77]D.A. Russell, 'The impact of IPM research', paper presented at the DFID NR Advisors' Conference, Sparsholt, UK, July 1997.

[78]K.A. Jones, 'IPM in developing countries — the Sri Lanka Experience', *Pesticide News*, Vol 31, 1996, pp 4–5.

[79]C.I. Nicholls and M.A. Altieri, 'Conventional agricultural development models and the persistence of the pesticide treadmill in Latin America', *International Journal of Sustainable Development and World Ecology*, Vol 4, 1997, pp 93–111.

[80]Russell, *op cit*, Ref 77.

[81]ICRISAT, 'Integrated management of a groundnut pest on India's eastern coast', *Food from Thought*, No 1, ICRISAT, India, 1995.

[82]KARI, unpublished data.

[83]Pingali and Gerpachio, *op cit*, Ref 40.

[84]H. Warburton, F.G. Palis and P.L. Pingali, 'Farmer perceptions, knowledge and pesticide use practices', in P.L. Pingali and P.A. Roger, eds, *Impact of Pesticides on Farmer Health and the Rice Environment*, Kluwer Academic Publishers, and IRRI, Manila, 1995.

[85]Agrow, 277, 1997, p 18.

[86]Pingali and Gerpachio, *op cit*, Ref 40.

[87]M. Loevinsohn, 'Insecticide use and increased mortality in rural Central Luzon, Philippines', *The Lancet*, Vol 8546, 1987, pp 1359–1362.

[88]FAO, Programma de Cooperacion de la Organizacion de las Naciones Unidas para la Agricultura y la Alimentacion (FAO) y el Gobierno de Bolivia, Documento del Proyecto, Enero, 1997.

[89]*Ibid.*

[90]'The costs of pesticides', *Pesticide News*, Vol 39, 1998.

[91]Pingali and Gerpachio, *op cit*, Ref 40.

[92]Pingali and Gerpachio, *op cit*, Ref 40.

[93]Gressel, *op cit*, Ref 45.

[94]P.L. Pingali and C.B. Marquez, 'Herbicides and rice farmer health. A Philippine study', in R. Naylor, ed, *Herbicides in Asian Rice: Transitions in Weed Management*, Stanford University, and IRRI, Manila, 1997.

[95]IITA, *op cit*, Ref 16; Herren and Neuenschwander, *op cit*, Ref 41.

[96]Thomas and Waage, *op cit*, Ref 75; M.J. Way and K.L. Heong, 'The role of biodiversity in the dynamics and management of insect pests of tropical irrigated rice — a review', *Bulletin of Entomological Research*, Vol 84, 1994, pp 567-587.

[97]W.H. Settle, H. Ariawan, E.T. Astuti, W. Cahayana, A.L. Hakim, D. Hindayana, A. Sri Lestari and Pajarningsih, 'Managing tropical rice pests through conservation of generalist natural enemies and alternative prey', *Ecology*, Vol 77, 1996, pp 1975–1988.

[98]Way and Heong, *op cit*, Ref 96; K. Schoenly, T.W. Mew and W. Reichardt, 'Biological diversity in rice landscapes', in N.G. Dowling, S.M. Greenfield and K.S. Fischer, eds, *Sustainability of Rice in the Global Food System*, Pacific Basin Study Centre, and IRRI, Davis, CA, 1998, pp 285–299.

[99]P.B.K. Hazell, 'Changing patterns of variability in world cereal production', in J.R. Anderson and P.R. Hazell, eds, *Variability in Grain Yields: Implications for Agricultural Research and Policy in Developing Countries*, Johns Hopkins University, Baltimore, MA, 1989; D. Wood, 'The benign effect of some agricultural specialization on the environment', *Ecological Economics*, Vol 19, 1996, pp 107–111.

[100]Wood, *op cit*, Ref 99.

[101]Smale *et al*, *op cit*, Ref 60; Smale *et al*, *op cit*, Ref 62; R.M. Rejesus, M. Smale and M. van Ginkel, 'Wheat breeders' perspectives on genetic diversity and germplasm use: findings from an international survey', *Plant Varieties and Seeds*, Vol 9, 1996, pp 129–147.

[102]Otsuka *et al*, *op cit*, Ref 58; Greenland, *op cit*, Ref 62; Pingali and Hossain, *op cit*, Ref 62.

[103]*Op cit,* Ref 62.

[104]Conway, *op cit,* Ref 29.

[105]Harrington, *op cit,* Ref 62.

[106]Padmanabhan, *op cit,* Ref 35; M.S. Swaminathan, 'Plant protection for global food security', *Proceedings of the 10th Plant Protection Congress,* Brighton, November 1983, pp 5–12.

[107]A. Sen, *Poverty and Famines: an Essay on Entitlement and Deprivation*, Clarendon Press, Oxford, 1981.

[108]*Ibid.*

[109]Pinstrup-Andersen *et al*, *op cit,* Ref 15.

[110]G.E. Schuh, 'The household: the neglected link in research and programmes for poverty alleviation', *Food Policy,* Vol 25, 2000, pp 233–241.

[111]Harrington, *op cit,* Ref 62.

[112]A. Krattiger, 'The importance of agbiotech to global prosperity', *ISAAA Briefs,* No 6, 1998.

[113]R.L. Thompson, 'Viewpoint: public policy for sustainable agriculture and rural equity', *Food Policy*, Vol 23, 1998, pp 1–7.

[114]Harrington, *op cit,* Ref 62.

[115]N.E. Borlaug, *Food Security, Plant Pathology and Quarantine,* Public Forum Discussion on the Role of Plant Pathology in Global Food Security, 7th International Congress of Plant Pathology, Edinburgh, August 1998.

[116]*Ibid.*

[117]Hossain, *op cit,* Ref 23.

[118]Byerlee and Eicher, *op cit,* Ref 68.

[119]D. Wood and J.M. Lenné, *Agrobiodiversity: Characterization, Utilization and Management,* CABI, UK, 1999.

[120]Lipton and Longhurst, *op cit,* Ref 7.

[121]Tripp, *op cit,* Ref 26.

[122]Pingali and Gerpachio, *op cit,* Ref 40.

[123]Pingali and Marquez, *op cit,* Ref 94.

[124]WARDA, *op cit,* Ref 16.

[125]IRRI, *op cit,* Ref 20.

[126]Thompson, *op cit,* Ref 113.

[127]Carney, *op cit,* Ref 5; C. Ashley and D. Carney, *Sustainable Livelihoods: Lessons from Early Experience,* DFID, London, 1999.

[128]Warburton and Martin, *op cit,* Ref 48.

[129]J. Kerr and S. Kovalli, 'Impact of agricultural research on poverty alleviation: conceptual framework with illustrations from the literature', paper prepared for the IAEG by IFPRI, Washington, DC, 1999.

[130]Pinstrup-Andersen *et al, op cit,* Ref 14; Pinstrup-Andersen *et al, op cit,* Ref 15.

[131]UNDP, *op cit,* Ref 8.

[132]Pinstrup-Andersen *et al, op cit,* Ref 14; Pinstrup-Andersen *et al, op cit,* Ref 15.

[133]UNDP, *op cit,* Ref 8; Pinstrup-Andersen *et al, op cit,* Ref 15.

[134]Pinstrup-Andersen *et al, op cit,* Ref 15.

[135]D. Bigman and M. Loevinsohn, 'Targeting agricultural research and development for poverty reduction: general principles and an illustration from Sub-Saharan Africa', paper presented at the CIAT Workshop on the Impact of Agricultural Research on Poverty Reduction, San José, Costa Rica, September 1999.

[136]Rohrbach, personal communication.

[137]Hazell, *op cit,* Ref 21.