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Review

The benefits of pesticides to mankind and the environment

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Abstract

Most published material relating to pesticides focuses on negative attributes and outcomes. This fact probably partly explains the public's inaccurate perception of the hazard they represent, and the low level of appreciation of the benefits they bring. This paper explores and analyses the many benefits of using pesticides, in order to inform a more balanced view. It does not attempt to quantify or rank these benefits, nor to weigh them against any negative consequences of pesticide use. Twenty-six primary benefits are identified that are immediate and incontrovertible, and 31 secondary benefits that are longer term, less intuitive and for which it is harder to establish causality. These benefits include increased crop and livestock yields, improved food safety, human health, quality of life and longevity, and reduced drudgery, energy use and environmental degradation. A complex matrix of benefit interactions are explored for a range of beneficiaries at three main levels—local, national and global, and in three main domains—social, economic and environmental.

Keywords: Pesticide; Application; Effect; Primary benefit; Secondary benefit; Risk; Beneficiary; Agriculture; Public health; Economy; Pests; Diseases

Contents

1. Introduction

The hazards of pesticides are well documented, but their benefits are largely ignored in published literature and the mass media. A recent brief poll of pesticide-related articles in published literature, conducted by the authors, revealed a ratio of over 40 negative articles for each one that took a more positive view. Many point to health or environmental problems from accidental or deliberate exposure to pesticides, particularly pesticides with high mammalian toxicity or those that persist in the environment. These risks should not be ignored, and efforts must be made to

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minimise them through rigorous regulation and proper training for users, but we should not overlook the positive impacts of pesticide use. When pesticides are used rationally and carefully, in conjunction with other technologies in integrated pest management systems, it is more likely that their use will be justifiable.

Part of the explanation for the scarcity of articles highlighting the benefits of pesticides may be that when a product does exactly what the manufacturer says it does, it is not 'newsworthy'. We do not read about the wonders of gloss paint, but it remains a good way to protect exterior woodwork. Sometimes, it takes an accident or evidence of harm to stir the popular media into action and this applies to some extent to scientific literature too.

There are some exceptions to the predominantly negative view of pesticides—Lomborg and Bjorn (2001) wrote "If pesticides were abolished, the lives saved would be outnumbered by a factor of around 1000 by the lives lost due to poorer diets. Secondary penalties would be massive environmental damage due to the land needs of less productive farming, and a financial cost of around 20 billion US Dollars".

This paper does not attempt to quantify or rank the benefits, nor to balance the benefits from pesticide use against any negative consequences. Rather it focuses on the positive outcomes delivered by judiciously used pesticides, in order to inform a more objective assessment of costs and benefits. It arises from an extensive literature search, the preparation of a comprehensive review report and the compilation of an electronic database of pesticide benefits for CropLife International. The key 100 or so articles will be available in the database, which will be publicly accessible via the CropLife website, as well as the full review report and bibliography of all 360 references (http://www.croplife.org/).

2. Perceived versus real risk

Like many technological developments that improve the quality of our lives, pesticides can pose risks if they are not used judiciously. In this they are not unique. Cars kill over 40,000 people each year in the US alone (Anon, 2003a). Their emissions contribute to greenhouse gases (Anon, 2006a) and they are inefficient users of energy compared with alternatives, such as buses or trains (Anon, 2006c). However, the convenience of being able to go from place to place independently is compelling, so many of us buy and drive cars. To reduce the risks and negative impact of car ownership, we legislate to make them safer (Likanen, 2001), and less polluting (EPA, 2000) and require drivers to pass a proficiency test to drive them. Likewise mains electricity brings irresistible benefits but there are some negatives too. Its production pollutes the atmosphere and causes 33% of greenhouse gases (Anon, 2006b) and there were 411 deaths in the US from accidental electrocution in 2001 according to the Product Safety Commission (2006). Similarly, few people would deny that medicines can reduce disease and preserve life, but if they are used without care they can be extremely hazardous. Berry (1991) pointed out that we accept the risks associated with selling the analgesic drug paracetamol over the counter in packets of five lethal doses, due to the benefits of easy access to pain relief and the improvement in life quality that it brings. These examples provide parallels with pesticides, being technologies that make our lives better, provided they are regulated and used in such a way that the benefits significantly outweigh the risks.

The potential benefits are particularly important in developing countries, where pests cost billions of dollars in national income (Anon, 2004b) and farm and post-harvest losses contribute to hunger and malnutrition, which kills between 12 million (UNICEF undated) and 15 million children annually (Anon, 2005a). According to the United Nations Children's Fund (UNICEF) malnutrition is: "largely a silent and invisible emergency, exacting a terrible toll on children and their families" (Bellamy, 1998).

Weighing the risks against the benefits of pesticide use is not only hampered by the paucity of information on benefits, but also by the fact that most people are poor judges of the relative hazard that pesticides represent. Based on earlier US data by Upton (1982), Hibbitt (1990) ranked 30 hazards on the criterion of number of deaths per year, with number 1 being the largest number of deaths and number 30 being the smallest. Pesticides were ranked very low at number 28 behind food preservatives (ranked 27), home appliances (ranked 15), swimming (ranked 7) and smoking and alcohol (ranked 1 and 2, respectively). But public perceptions were very different. Women voters thought that pesticides ranked number 9 in the list, and college students put them at number 4. Both groups performed poorly at estimating the relative risks posed by a list of hazards, perhaps due to the predominantly negative publicity that pesticides receive.

Moreover, food safety and health concerns in the general public have increased in Europe following serious incidents such as Salmonella poisoning, Bovine Spongiform Encephalopathy (BSE), Foot and Mouth and *Escherichia coli* infections. Pesticide residues in food, detected at ever-lower levels due to increasingly sensitive laboratory equipment, are perceived to be associated with these issues and are lumped together with them as another of the evils of agricultural intensification. However, the evidence does not support the popular view that pesticide residues represent a significant health risk in Europe and the US.

Statutory maximum residue levels (MRLs) are the highest concentration of pesticide (expressed in mg/kg) legally permitted in or on food commodities and animal feed. They are set by measuring the residue levels on harvested produce after it has been grown using Good Agricultural Practice and in accordance with pesticide label instructions, provided this level does not constitute a hazard to consumers. In fact, contrary to public perception, MRLs are far below any level that would be hazardous to consumers—they are usually not approved unless they are a factor of at least 100 below the no observable adverse effect level (NOAEL). The UK Pesticide Residue Committee annual report (2002) found that over 70% of the food in the UK contained no detectable pesticide residues and only 1.09% contained residues above the statutory MRLs. It concluded that "none of these residues caused concern for people's health". This is backed up by Brown (2004) and by Bell (2005), Head of the UK Food Standards Agency, who said "There are no safety concerns or we would take action immediately".

3. Types of positive outcome from pesticide use

There is a large range of positive outcomes from different types of pesticide use. Reduced crop loss resulting from spraying fungicides is an obvious benefit, but some are less obvious either because they occur in the medium or long term, or are subtle or small incremental benefits distributed over a large area. To facilitate a systematic analysis capable of unravelling the many potential benefits of pesticide use, a hierarchical model of outcomes was adopted, comprising effects, primary benefits and secondary benefits.

3.1. Effects

Effects are the immediate outcomes of pesticide use—for example killing caterpillars on a cabbage. These are not classed as benefits because the consequences of the effects have not manifested themselves yet. The three main *effects* of pesticides are:

(1) controlling agricultural pests (including diseases and weeds) and vectors of plant disease;
(2) controlling human and livestock disease vectors and nuisance organisms;
(3) preventing or controlling organisms that harm other human activities and structures.

3.2. Primary benefits

These are the consequences of the pesticides' effects—the direct gains expected from their use. For example, the effect of killing caterpillars prevents them feeding on the crop and brings the primary benefit of higher yields and better quality of cabbage. From the three main effects listed above, 26 primary benefits have been identified ranging from protection of recreational turf to saved human lives.

3.3. Secondary benefits

These are the less immediate, less intuitively obvious, or longer term consequences. It follows that for secondary benefits, it is more difficult to establish cause and effect, but nevertheless they can be powerful justifications for pesticide use. For example, higher cabbage yield might bring additional revenue that could be put towards children's education or medical care, leading to a healthier, better educated population. There are 31 secondary benefits identified here, ranging from fitter people to conserved biodiversity.

Fig. 1 summarises effects, primary and secondary benefits and their interactions. The interplay between the effects and benefits is complex and not easy to follow in this diagram. However, the detail of the linkages is less important at this stage than the recognition that there are many and varied positive downstream implications arising from pesticide use—some more obvious, and some less so.

4. Beneficiaries and the domains and dimensions of benefit

The number and type of people who benefit (or suffer) due to a technology influence our attitudes to it. A common public misconception is that the only benefit of pesticides is to increase the profits of wealthy farmers. In fact, beneficiaries of pesticide use include consumers, retailers, drivers, researchers, politicians and individuals from many other groups. Poor people are as likely to benefit as wealthier ones. However, a detailed analysis of the beneficiaries and the distribution of benefits among them is beyond the scope of this paper.

There are three main benefit domains: the social domain concerns issues such as the health, life quality and well-being of people; the economic domain concerns issues such as farm revenues, costs and profits; and the environmental domain covers issues of the aquatic, terrestrial and airborne environment, including global warming. Benefits in these domains can operate at community, national or global scales. For example, the use of herbicides saves money or effort on mechanical weed control at the community level, brings medium term social benefits of reduced drudgery, improvement of the living environment on public and personal-use amenity or sports-use land at national levels, and longer term environmental benefits of reduced fossil fuel use, soil disturbance and moisture loss from tillage—a global scale benefit to us all. These domains and dimensions are mentioned where relevant in the exploration of benefits that follows, and the benefits are categorised according to them later in Fig. 5.

4.1. The benefits of effect 1—controlling pests and plant disease vectors

Over the last 60 years, farmers and growers have changed the way they produce food in order to meet the expectations of consumers, governments and more recently, food processors and retailers. In doing so, they have made many changes to the way they farm, including the extensive use of pesticides. They have done this principally to prevent or reduce agricultural losses to pests, resulting in improved yield and greater availability of food, at a reasonable price, all year round. Pimentel (1997) suggests there is a four-fold return on investments in pest control and Pimentel et al. (1992) estimated an economic return of around $16 billion from pesticide use in the USA. India, a former country of famine has quadrupled grain production since 1951 (Jha and Chand, 1999) and now not only feeds itself but exports produce. Similarly outputs and

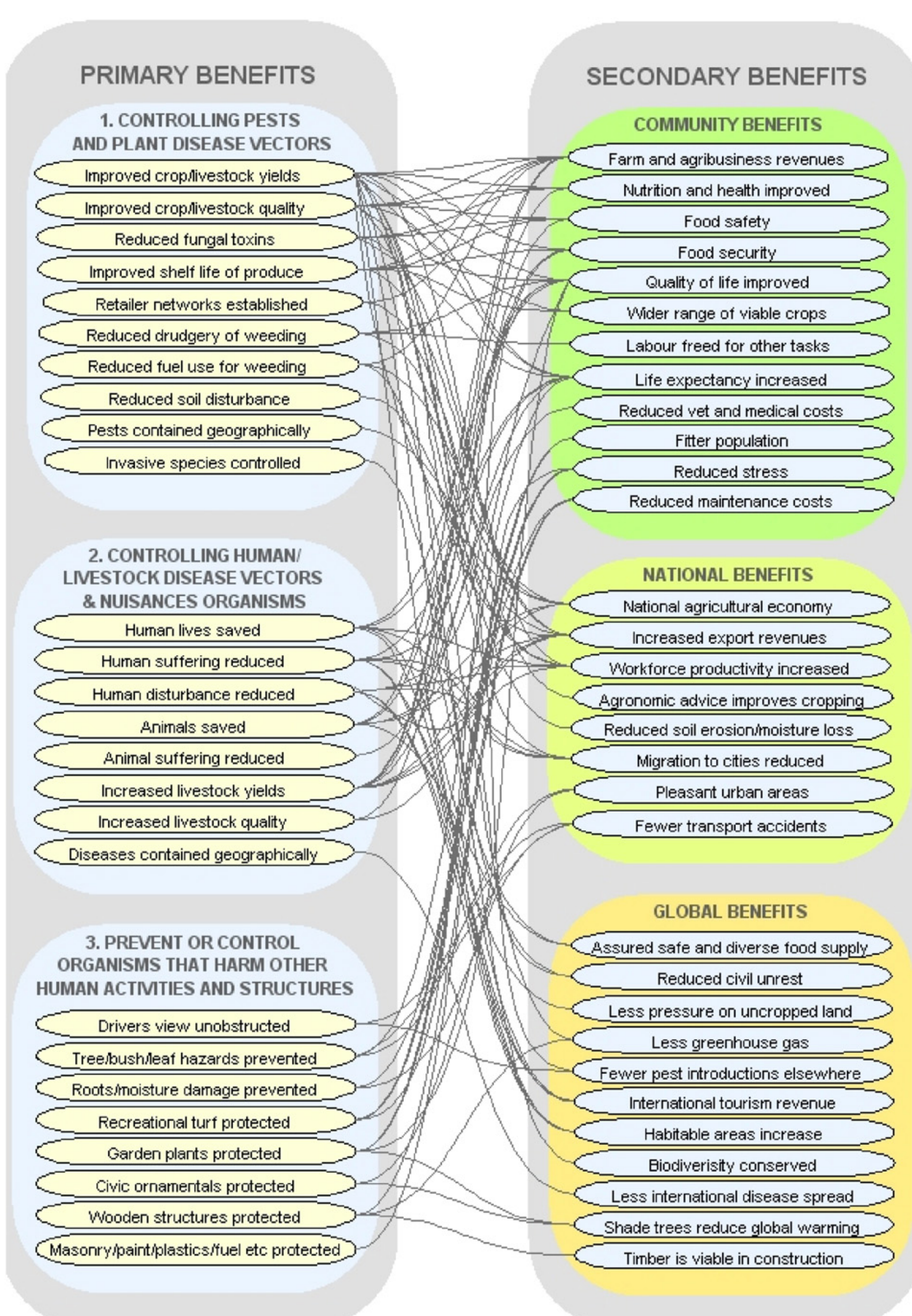

Fig. 1. Effects, primary and secondary benefits. The linkages are not easy to follow, but serve to illustrate the complexity of the interactions between them.

productivity have increased dramatically in most countries, for example, wheat yields in the United Kingdom rose from 2.5 t/ha in 1948 to 7.5 t/ha in 1997 (Austin, 1998). Corn yields in the USA went from 30 bushels per acre to over a hundred per acre over the period from 1920 to 1980 (Kucharik and Ramankutty, 2005). Warren (1998) also drew attention to the spectacular increases in crop yields in the United States in the twentieth century, reporting that average US yields for 10-year periods during this century for nine crops show that increases were from two to seven-fold, starting in the 1940s and continuing during the rest of the century. While a significant proportion of the gains are due to better soil and water management, improved plant varieties and application of fertiliser, the use of pesticides has undoubtedly played a very significant role. Webster et al. (1999) stated that "considerable economic losses" would be suffered without pesticide use and quantified the yield increases and 50% increase in gross margin that result from pesticide use in British wheat production. Webster and Bowles (1996) concluded that without pesticides, apple production would not be commercially viable and farmers would have to use their land for other purposes. In Russia, Petrusheva (1975) attributed orchard yield increases of 1.5–2 times to the use of pesticides. Damage done to fruits by the apple worm went down to 1–2%, and marketable percentage was 80–90% of produce when pesticides were adopted. In the same country, Zakharenko (1975), Keiserukhsky and Kashirsky (1975) and Chenkin (1975) all claimed that the financial outlay on pesticides was repaid four to six times in increased yields.

Not only do pesticides prevent losses on existing crops, they broaden the range of viable crop options that a farmer can grow at particular times of year. For example, tomatoes can only be grown in the rainy season in Zimbabwe by using fungicide to prevent late blight—without them, there is usually total crop failure. This rainy season production is also extremely lucrative; tomatoes have a highly elastic price response to demand, with rainy season prices being 10 times dry season prices (Mapurisana, 1998, personal communication).

Controlling pests of pasture can also bring significant livestock productivity benefits. By using a single carefully timed insecticidal spray costing US$10/ha to control red legged earth mite in clover, Australian sheep farmers have increased the value of their wool yield by US$50/ha (Ridsill-Smith and Pavri, 2000).

Herbicides are the most widely used type of pesticide since weeds are the major constraint that limit yield in many crops. Herbicides represent around 50% of all crop protection chemicals used throughout the world, compared with insecticides and fungicides that are around 17% each (CropLife, 2004, personal communication). Without herbicides there would be an estimated US $13.3 billion loss in farm income in the US (Anon, 2003b). Yancy and Cecil (2005) put the figure for benefits of herbicide use even higher at $21 billion annually, against a cost of $6.6 billion for the product and application that reduced losses to weeds by 23% and avoided a loss of farm income valued at $8 billion. Bridges (1992) reported that US losses due to weeds of $4 billion would be $20 billion without use of herbicides. Miller Stanley (1982) analysed the primary and secondary productivity and labour impacts of improved weed control, as achieved with herbicides, on farmers and rural communities. He concluded that increased agricultural productivity creates direct economic benefits for farming families in terms of increased income.

There are knock-on benefits of these primary benefits. If marketable yields and quality are increasing, farm revenues are also likely to increase. This results in wealthier farmers with more disposable income to stimulate the local economy. Higher yields mean less pressure to cultivate un-cropped land—a wider benefit to biodiversity and the environment as highlighted by McNeely Jeffrey and Scherr Sara (2003). In turn, regional and national agricultural economies become more buoyant and revenues from exports of high quality produce bring in much needed foreign exchange. This last factor is particularly important in some developing countries that export fruit and vegetables to the US and Europe, where the unintended presence of certain flora and fauna in the produce can be a major barrier to international trade (IPPC, 1997). Consumers in developed countries gain too from the wider range of imported crops that is available for a greater proportion of the year.

More food in communities also allows better nutrition, which carries over into healthier lives. Healthier people are by and large also happier people, who are more productive and able to contribute better to their society. This contrasts with the situation where poor nutrition resulting from limited food supplies increases the susceptibility to diseases, reducing people's energy and productivity in a vicious circle of deprivation. Pesticides can help break this cycle that threatens security of personal livelihoods and quality of life.

Reliability of production is economically important to any producer, and to resource-poor communities with no financial or food reserves, it is critically import. It is no good having an adequate harvest for 3 years if there are large losses in the fourth year. By reducing risk of catastrophic loss to pests and diseases, pesticides are a tool to help deliver food security and dependable livelihoods from farming.

Many people now expect and enjoy a healthier and longer life than in the past. Average life expectancy in the US, which was only 47 years in 1900 has now risen to 78 (Anon, 2005b). In France, life expectancies have increased by 3 months every year for the past 50 years (Atreya, 2006). Many lives are also more comfortable in the 21st century than those experienced by our ancestors who tended to work hard and die young. There are some unfortunate exceptions to this trend. For example, Zimbabweans now have a life expectancy of less than 40 due to HIV/Aids and failing medical and agricultural systems. In many other parts of the world, improved medical care and drug treatments with better living conditions and improved hygiene have played a significant role in extending lives, but the value of nutritious, safe and affordable food should not be underestimated as a health promoter that increases life expectancy (US Dietary Guidelines, 2005, European Food Information Council, 2006; Atreya, 2006; Eat 5 to 9 a day (US) and 5 a day campaign, UK, 2003).

Gattuso (2000) wrote that banning some pesticides would reduce the availability, affordability and overall consumption of fruit and vegetables—a vital protection against cancer. Lewis and Ruud (2004, 2005) discussed the nutritional properties of apples and blueberries in the US diet and concluded that their high concentrations of antioxidants act as protectants against cancer, heart disease, and other chronic diseases associated with oxidative stress and ageing. Lewis attributed doubling in wild blueberry production and subsequent increases in consumption chiefly to herbicide use that improved weed control. Gianessi and Leonard (1999) attributed all year round availability of inexpensive and good quality fresh fruit and vegetables largely to the use of pesticides.

Herbicides replace the back-breaking work of manual weeding, and reduce the fossil-fuel requirements for mechanical cultivation. The reduction in the need for manual weeding is particularly significant in sub-Saharan Africa where HIV/AIDS has resulted in shortages of labour and many adults being too ill to work (Hainsworth et al., 2000).

When herbicides are used, what little labour there is available can be freed for other productive activities.

Improved nutrition and reduced drudgery clearly both improve the quality of life of rural communities, and while 'quality of life' is imprecise and difficult to define, it is surely what most people are seeking to improve—whether it be through money, work satisfaction, home life or more time for recreation. An improved quality of rural life can contribute to a slowing down of the dramatic rural to urban exodus, as people try to escape the poverty and suffering of agricultural communities, only to find themselves in deeper poverty in town with no viable livelihood options.

The opportunities afforded by herbicides to reduce mechanical cultivation in larger scale agriculture clearly have wider national and international benefits in reduced production of greenhouse gases, as well as slowing down soil erosion on sloping land, and reducing moisture loss from soil surfaces (Bates and Denton, 2007, undated; Anon, 2005c).

Pesticides can also improve the quality of the produce (Kolbe, 1982) including its safety. When stressed or attacked by diseases, many plants, or the pathogenic organisms causing the diseases, produce chemicals that are acutely toxic. An extreme example is the cereal disease ergot (*Claviceps purpurea*) that produces highly toxic and sometimes lethal alkaloids in the grain under certain conditions unless protected by a fungicide. One family of mycotoxins, the aflatoxins, are potently carcinogenic and immunotoxic and can cause growth retardation when consumed. Fumonism (a toxin associated with Fusarium, that causes brain and kidney damage) can also affect both humans and animals. These mycotoxins proliferate in maize grain and other crops either in the field or in storage when temperature and humidity conditions are favourable for them (Bruns and Arnold, 2003). The use of fungicides can reduce the incidence of such fungal contaminants (Joshi, 2001). Etcheverry et al. (1987) studied the influence of 10 commercial fungicides and insecticides on growth and formation of aflatoxin B1 by *Aspergillus parasiticus*. Four of the five fungicides investigated in concentrations corresponding to commercial practice inhibited growth and toxin production in the laboratory media.

Pesticides used in stored products can prolong the viable life of the produce and prevent huge post-harvest losses from pests and diseases. Dales and Golob (1997) reported that insecticides can protect stored grain in bags or bins from insect spoilage. Their trials in Tanzania showed that the larger grain borer *Prostephanus truncatus* and *Sitophilus* species can be controlled for at least 9 months by applications of insecticide mixtures used in small quantities as protectants of shelled maize. Zettler and Arthur (2000) also reported on chemical control of stored product insects with fumigants and residual treatments, and wrote that pesticides are often the cheapest and most efficient control strategy available.

Effective control of pests can have consequences beyond the geographic or chronological range of the initial intervention. If pest levels are suppressed by many farmers at once, it can have an area-wide effect—in other words, the source population for infection or infestation of future crops is reduced. In many cases, the threat to subsequent crops is therefore much lower, even without future interventions.

For more mobile pests such as locusts, if populations can be controlled before they become too numerous in one country, it can prevent massive population expansion and migration to other countries (Anon, 2001). Non-pesticidal approaches such as egg bed destruction, digging trenches and burying the nymphs or beating them with branches are all too slow and act on too small a scale to have any significant impact on the overall locust populations in the area. The early interventions over large areas that are possible with aerially applied insecticides can be more cost-effective and environmentally safe than the later 'fire brigade' treatments over much larger areas and longer time periods that would otherwise be required.

Pests controlled effectively on export crops can prevent pest introductions in other countries—a phenomenon that often has devastating effects due to the fact that the new pest has left behind all of its natural enemies, i.e. its predators and parasitoids that were exerting a natural regulatory pressure on the pest in its native region (Neuenschwander and Peter, 2001). Moreover, pesticides are a powerful tool against invasive species that constitute an enormous threat to indigenous ecologies. For example, when rats are introduced onto islands previously free of them, they have a devastating effect on local fauna—in particular, on ground-nesting birds, but also other mammals, molluscs, insects, spiders, amphibians and reptiles. In this way, pesticides can be a tool to conserve biodiversity (Fig. 2).

4.2. Benefits of effect 2—controlling human/livestock disease vectors and nuisance organisms

In warmer climates especially, insects can spread devastating human diseases such as malaria, sleeping sickness, river blindness and a range of serious fevers and disfiguring or debilitating illnesses. Ross (2005) reported that malaria kills more than 5000 people every day. Lindblade et al. (2004) argue that this figure urgently needs to be reduced by use of insecticide-treated bed nets—particularly the high levels of infant mortality. Field trials by Yadav and Sampath (2001) showed that bed nets treated with deltamethrin significantly reduced indoor resting density, biting, light trap catches, human sourced engorgement rate and parous rate of malaria infection in *Anopheles* mosquitoes. Malaria incidence was reduced 59% in the treated net village, 35% in the untreated net village, and 9% in the no-net village. Curtis et al. (2003) reported that use of treated bed nets reduced the number of infective bites per person per year by 75%. Half of this effect is attributable to an area-wide effect of reducing mosquito populations due to the nets killing those attracted to the human 'bait'. The other half of the effect is due to the personal protection afforded by the treated nets. Lindblade et al. (2004) pointed out that insecticide treated bed nets

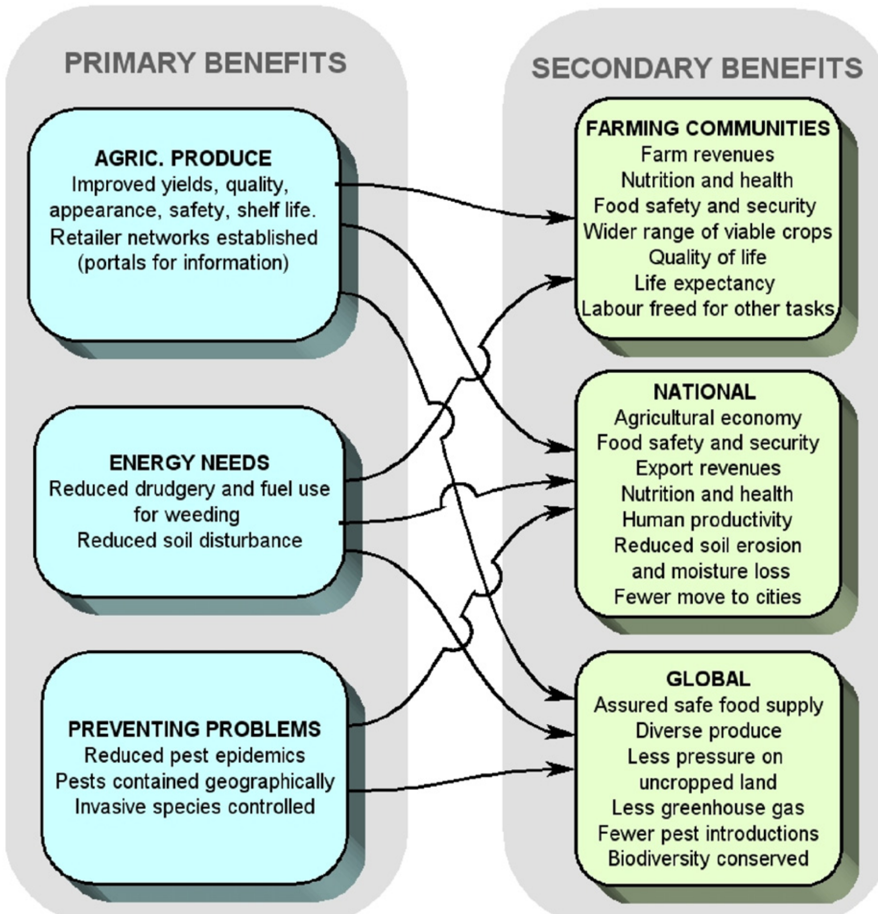

Fig. 2. Benefits of pesticide effect 1. Using pesticides to control pests (including diseases and weeds) and vectors of plant diseases.

significantly reduced infant mortality in western Kenya with no increased mortality in older children through delayed acquisition of immunity to malaria (an argument sometimes voiced against use of nets).

Gratz (1994) asserted that vector-borne diseases are most effectively tackled by killing the vector. Insecticides are often the only practical way to control vectors, but are being under-exploited (Townson et al., 2005). The World Health Organization (Anon, 2004c) claims that without access to chemical control methods, life will continue to be unacceptably dangerous for a large proportion of mankind. Recognising this, nearly 30 years after phasing out the widespread use of indoor spraying with DDT and other insecticides to control malaria, the World Health Organization (WHO) announced that this intervention will once again play a major role in its efforts to fight the disease. WHO is now recommending the use of indoor residual spraying (IRS) not only in epidemic areas but also in areas with constant and high malaria transmission, including throughout Africa (http://www.who.int/mediacentre/news/releases/2006/pr50/en/index.html).

Insects such as cockroaches and houseflies are mechanical vectors for various micro-organisms that cause diarrhoeal diseases, which are rated by UNICEF as the number one killer of children under 5.

The most obvious benefit of controlling the wide range of human and livestock disease vectors is reduced suffering and lives saved that would otherwise have been lost, but reducing the likelihood of international spread of disease is not insignificant. With regard to livestock, controlling disease vectors translates to secondary benefits of additional livestock revenue and reduced veterinary and medicine costs. Kamuanga (2001) in Burkina Faso reported that tackling trypanosomiasis through tsetse control programs using insecticide-impregnated targets and pour-on treatments of all cattle with deltamethrin 1% resulted in benefits which included; a 25% increase in herd size and an increase in the number of oxen from 0.1 to 1.1 per household; a reduction in mortality from 63.1% to 7.1% and reductions in the rates of abortions and stillbirth of 55.9% and 51.3%, respectively; and an increase in the rate of live births of 57.6%, as well as increases in the milk yield from 0.2 to 2.2 l/cow/day in the dry season. In Ethiopia where the main vector of malaria (*Anopheles arabiensis*) feeds on cattle as well as on humans, when cattle were treated to control tsetse fly, intriguingly, local people told him that not only were their cattle healthier but they also noticed that the incidence of malaria was reduced. It seems probable that insecticide-treated cattle could reduce malaria transmission too (Torr, personal communication). The higher livestock yields and quality provide a boost to the national economy and may allow access to meat export markets, generating valuable foreign exchange (Fig. 3).

In the case of humans, lower vector-borne disease incidence increases life expectancy and leads to a happier society, more confident in its future. Most fatalities from malaria are in young children and pregnant women. A reduction in infant mortality is usually correlated with a decrease in family size—people have fewer children if they think they are more likely to survive. Children in these smaller families are better cared for and have better nutrition and life quality. Ensuring the survival of pregnant women ensures there is a carer for her children and has a knock on effect on the well-being of communities. When serious vectors and nuisance insects are controlled, previously uninhabitable areas become habitable and quality of life increases in both rural and urban environments.

There are also substantial benefits to reducing the number of people suffering sub-lethal effects of vector-borne diseases. The misery caused by frequent bouts of malaria or the insidious effects of river blindness on eyesight has a debilitating effect on the morale and productivity of communities, not to mention the cash cost of medicines to treat these diseases. Moreover, studies by Hoffman et al. (1999) have shown that acute malaria infection increases HIV viral load, and that this increased viral load was reversed by effective malaria treatment. This malaria-associated increase in viral load could lead to increased transmission of HIV and more rapid disease progression, with substantial public health implications.

A less obvious, but still significant benefit is the prevention of misery and disturbance caused by various biting insects, whether they transmit disease or not. This group includes mosquitoes, blackflies, midges, other biting flies, fleas, lice and bedbugs. Studies in Cameroon have found people in some areas being bitten up to 2000 times per day by *Simuliid* blackflies, effectively preventing them doing any useful agricultural or other outdoor work due to the nuisance and constant irritation. An additional non-lethal but nonetheless disfiguring effect of these bites is depigmentation of the skin, which causes social stigmatisation and inability to find life partners. The whining noise of mosquitoes flying—especially *Culex* species—disturbs people and prevents them sleeping properly.

The impact of biting flies is not confined to the developing world. America, Canada and many other countries use pesticides to control ticks, mosquitoes, blackflies and other insects so that people can live more comfortably and enjoy their recreation undisturbed. If such insects were not controlled, there would be a severe impact on life quality, tourism levels and revenue. Recent arthropod-borne disease episodes in the developed world, particularly West Nile virus and Lyme disease in the US and Ross River virus in Australia, have drawn attention to the potential for biting insects to transmit serious diseases even in the developed world.

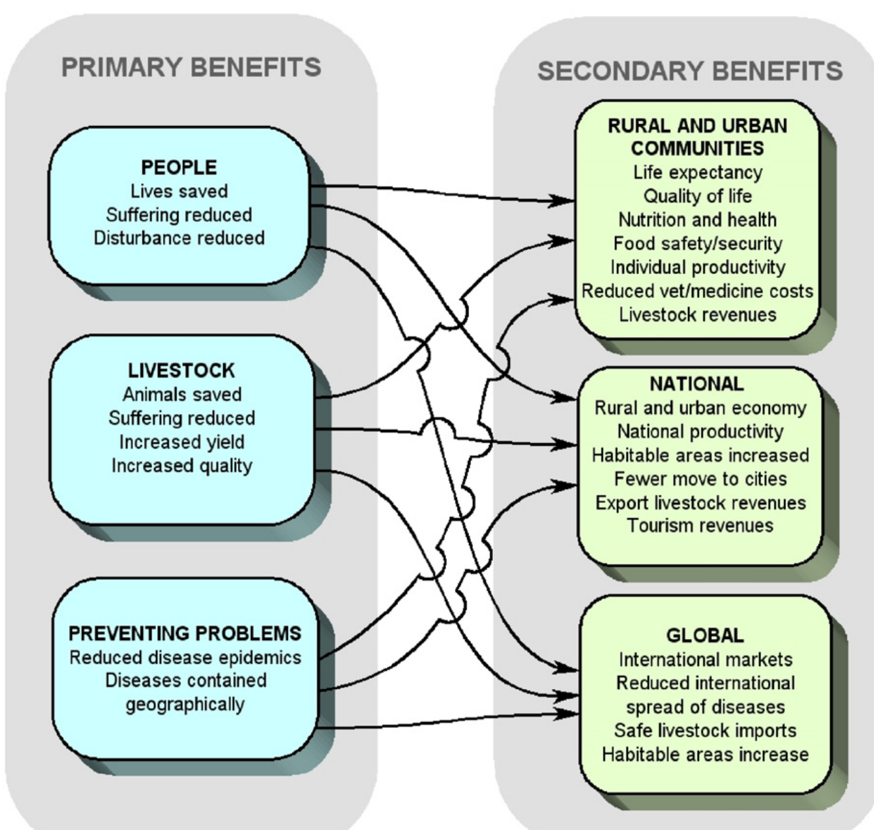

Fig. 3. Benefits of pesticide effect 2. Controlling human and livestock disease vectors and nuisance organisms.

4.3. Benefits of effect 3—preventing or controlling organisms that harm other activities or damage structures

In the same way that pests in agriculture and public health cause undesirable effects such as losses, spoilage and damage, various organisms have a negative impact on human activities, infrastructure and the materials of everyday life unless controlled. Pesticides play an important, if often unseen role in preventing this negative impact.

The transport sector makes extensive use of pesticides, particularly herbicides, to ensure that roads, railways and waterways are kept free of vegetation that might otherwise cause a hazard or nuisance. For example, if vegetation is allowed to grow too tall on roadsides, it reduces the drivers' view at junctions, and deposits branches or vegetation onto the road that might be an obstruction or make it very slippery. The use of pesticides to manage this vegetation brings secondary benefits of safer transport systems with fewer accidents and less stress for users.

An invasive species that can obstruct waterways is the water hyacinth. It was introduced from South America in the 1950s into many countries as an ornamental plant and it can also provide livestock food and can control pollution by absorbing heavy metals. Unfortunately, the species reproduced rapidly and spread over many countries, out-competing other plants for space and water and clogging rivers, lakes and dams. Due to their great thirst for water, arid countries in Africa have recently spent an estimated US$60 million annually to control alien weeds such as water hyacinth (Anon, 2004a). The Worldwide Fund for Nature programme clears alien plants from 200,000 ha per annum. Some biological control programmes are in place, but they are insufficient to deal with the problem exhaustively. The programme is now using herbicides, which have proved to be very useful in dealing with invasive species (Anon, 2004a).

Pesticides are also used on water craft to prevent the build up of algae, molluscs, and weeds, and deliver secondary benefits of reduced costs of manual cleaning, and increased fuel efficiency from the reduced drag of a smooth hull.

The destructive power of vegetation is also enormous; above ground growth around metal structures harbours moisture and can accelerate corrosion, and below ground, the roots of growing plants can crack pipes, open up potholes in the road or dislodge railway lines. Most people living in towns take for granted that roads, gutters and pavements stay clear and weed-free, and are not aware that it is due to the regular use of herbicides. Thus, pesticides bring primary benefits associated with preventing these problems, leading to secondary benefits of reduced maintenance costs and increased transport safety.

In an age of increasingly sedentary jobs, sport and recreation are very important for people's physical and mental health. Herbicides and insecticides are used to maintain the turf on sports pitches, cricket grounds and golf courses and so help to bring secondary benefits of improved health and fitness, reduced stress, and greater quality of life.

Similarly, the pesticides used in domestic gardens enable householders to maintain their plants—edible or ornamental—and protect them from pests and diseases. Gardening is the most popular leisure activity in the United Kingdom and pesticides are helping to facilitate a hugely popular pastime that provides fresh air and exercise for millions of people around the world, contributing to their health, fitness and quality of life. The result of their efforts is reflected economically in several ways. Exercise promotes health and reduces medical needs, and pleasant gardens add significantly to the value of properties (Ravlin and Robinson, 1985; Henry and Environ, 1994). Ornamental plants and trees in public spaces are also protected from pests and diseases by the use of pesticides where necessary, and such civic vegetation makes urban landscapes more pleasant to live in, thus improving life quality and reducing stress. Plants—particularly tress—provide shade in hot countries, which can reduce cooling energy costs (Templeton et al, 1998), and trees are used as windbreaks in exposed sites to protect crops from damage (Fig. 4).

Insecticides protect buildings and other wooden structures from damage by termites and wood boring insects, thus decreasing maintenance costs and increasing longevity of buildings and their safety. This use also has wider environmental benefits in that timber—a renewable resource that can be produced in an environmentally beneficial way—becomes a more viable construction material.

Antimicrobial pesticides, sometimes known as biocides, are substances used to destroy or suppress the growth of harmful micro-organisms such as bacteria, viruses, or fungi that can cause spoilage, deterioration or fouling of materials in applications such as cooling towers, jet fuel, paints, textiles and paper products. Secondary benefits are greater shelf life and longevity of products and reduced maintenance costs.

5. Categorisation of benefits by domain and dimension

When the many benefits are laid out in a matrix (Fig. 5), the linkages are easier to follow than in Fig. 1. The colour coding also allows them to be categorised by domain—social, economic and environmental—and by dimension—local, national or global. The construction of this matrix was informed by the large body of literature reviewed, but also by experience, deduction and extrapolation—particularly the secondary benefits where direct evidence linking use to benefit is harder to find.

The results suggest that at community level, most of the benefits are social, with some compelling economic benefits too. At the national level, the benefits are principally economic, with some social benefits and one or two environmental benefits. It is only at the global level that the environmental benefits appear to come into play. To some extent, this is an over-simplification as a result of trying to categorise the benefits and avoid repetition, for example, the benefit of reduced soil erosion and moisture loss that

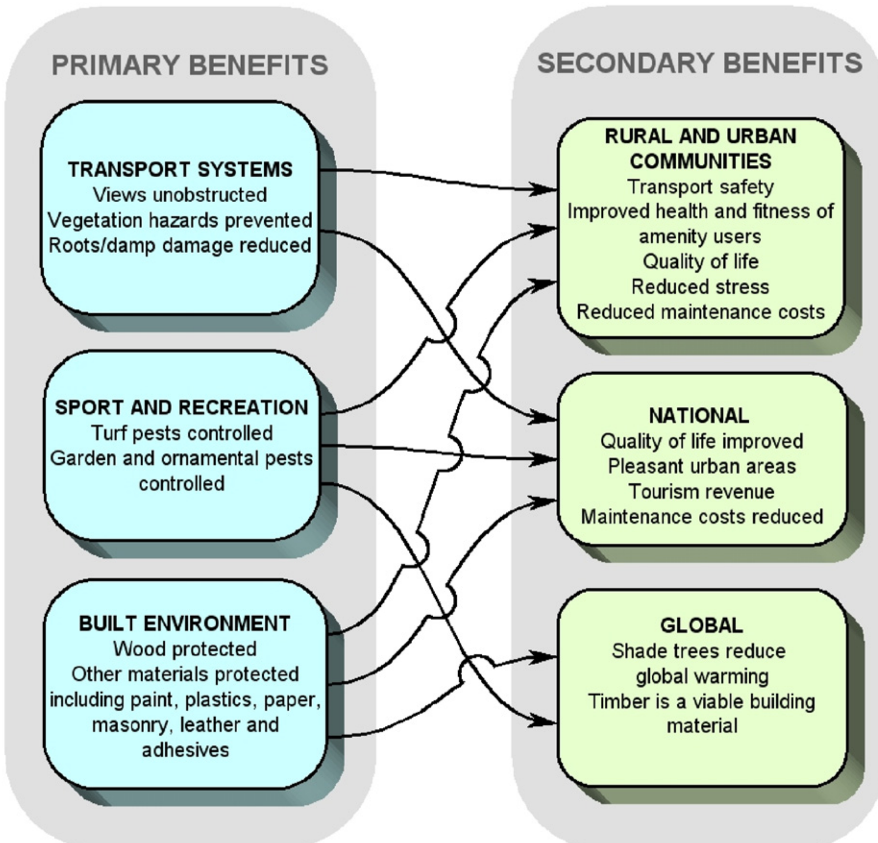

Fig. 4. Benefits of pesticide effect 3. Prevent or control organisms that harm other human activities or structures.

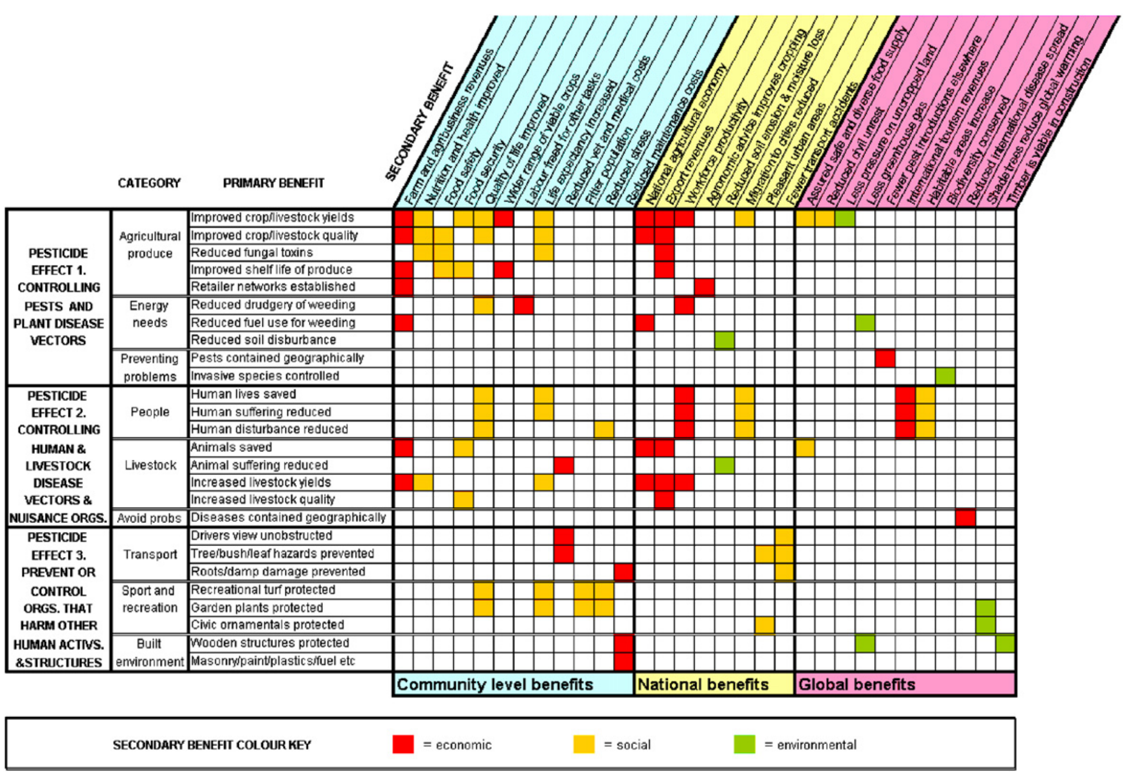

Fig. 5. Matrix of pesticide effects, and primary and secondary benefits.

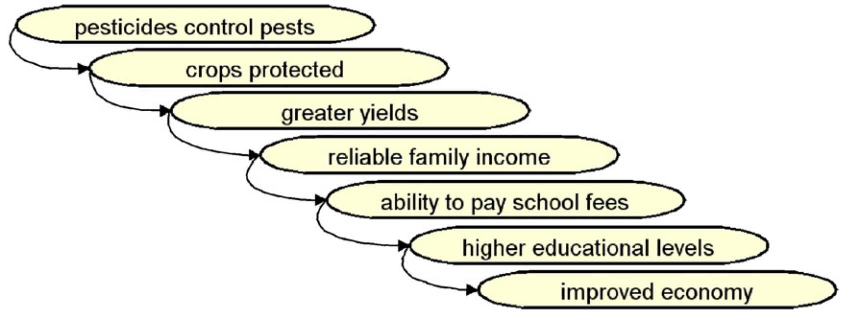

Fig. 6. Example of a chain of benefits.

currently sits in the national benefits area, applies equally to communities. And of course global environmental benefits are eventually felt at every level.

6. Discussion and conclusions

The risks associated with pesticide use have been set aside in order to focus on the benefits of pesticides and redress the balance of information available for a more objective assessment of costs and benefits. In addition, there has been no attempt to quantify or rank the benefits.

In considering ways to categorise and summarise the beneficial outcomes of pesticide use, it became clear that while the initial effects are usually obvious, and primary benefits follow on reasonably logically, there are secondary (and subsequent) benefits that are sometimes quite subtle and more difficult to substantiate. One such pathway illustrated below in Fig. 6 proposes some indirect but important consequences of pesticide use for resource-poor families and ultimately the economy.

However, as we try to track these events, many other factors come into play in an increasingly complicated series of interactions in which it is difficult to be sure there is cause and effect. And indeed, while the example cited above is a plausible chain of benefits, we are unlikely to find documentary evidence in individual publications that follow them right through because the chain spans such a wide range of disciplines—chemistry, economics, sociology, education. Where would it be published? So while there is plentiful evidence linking pesticide effects to primary benefits, in order to link the primary benefits to the secondary and subsequent ones and validate the complete chain of benefits, it would be necessary to review literature outside the body of publications related to pesticides, or to carry out extensive multi-disciplinary field research.

The hierarchical model of effects, primary benefits and secondary benefits helped in the unravelling and categorisation of potential benefits of using pesticides. Although there was inevitable simplification in the categorisation process, it is clear that the benefits are many and diverse and can operate in all domains and dimensions, and across all countries rich and poor.

There are many other technologies that parallel pesticides, such as vehicular transport and the mains electricity supply, in that they bring us enormous net benefits provided the associated risks are properly managed. However, to maximise the benefits of pesticide use at minimum human, environmental and economic cost, pesticides must be strictly regulated and used judiciously by properly trained and appropriately equipped personnel, ideally in tight integration with other complementary technologies.

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