Chapter 2
Environmental and Economic Costs of the Application of Pesticides Primarily in the United States

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Contents

Abstract An obvious need for an updated and comprehensive study prompted this investigation of the complex of environmental and economic costs resulting from the nation's dependence on pesticides. Included in this assessment of an estimated $9.6 billion in environmental and societal damages are analyses of: pesticide impacts on public health; livestock and livestock product losses; increased control expenses resulting from pesticide-related destruction of natural enemies and from

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the development of pesticide resistance in pests; crop pollination problems and honeybee losses; crop and crop product losses; bird, fish, and other wildlife losses; and governmental expenditures to reduce the environmental and social costs of the recommended application of pesticides.

The major economic and environmental losses due to the application of pesticides in the USA were: public health, \$1.1 billion year; pesticide resistance in pests, \$1.5 billion; crop losses caused by pesticides, \$1.4 billion; bird losses due to pesticides, \$2.2 billion; and groundwater contamination, \$2.0 billion.

Keywords Agriculture · Costs · Crops · Environment · Livestock · Natural resources · Pesticide · Pesticide resistance · Public health

2.1 Introduction

Worldwide, about 3 billion kg of pesticides is applied each year with a purchase price of nearly \$40 billion year^{-1} (PAN-Europe 2003). In the USA, approximately 500 million kg of more than 600 different pesticide types are applied annually at a cost of \$10 billion (Pimentel and Greiner 1997). Despite the widespread application of pesticides in the United States at recommended dosages, pests (insects, plant pathogens, and weeds) destroy 37 % of all potential crops (Pimentel 1997). Insects destroy 13 %, plant pathogens 12 %, and weeds 12 %. In general, each dollar invested in pesticide control returns about \$4 in protected crops (Pimentel 1997).

Although pesticides are generally profitable in agriculture, their use does not always decrease crop losses. Despite the more than 10-fold increase in insecticide (organochlorines, organophosphates, and carbamates) use in the United States from 1945 to 2000, total crop losses from insect damage have nearly doubled from 7 to 13 % (Pimentel et al. 1991). This rise in crop losses to insects is, in part, caused by changes in agricultural practices. For instance, the replacement of corn-crop rotations with the continuous production of corn on more than half of the corn acreage has resulted in an increase in corn losses to insects from about 3.5 to 12 % despite a more than 1000-fold increase in insecticide (organophosphate) use in corn production (Pimentel et al. 1991). Today corn is the largest user of insecticides of any crop in the United States.

Most benefits of pesticides are based on the direct crop returns. Such assessments do not include the indirect environmental and economic costs associated with the recommended application of pesticides. To facilitate the development and implementation of a scientifically sound policy of pesticide use, these environmental and economic costs must be examined. For some time, the US Environmental Protection Agency pointed out the need for such a benefit/cost and risk investigation (EPA 1977). Thus far, only a few scientific papers on this complex and difficult subject have been published.

2.2 Public Health Effects

2.2.1 Acute Poisonings

Human pesticide poisonings and illnesses are clearly the highest price paid for all pesticide use. Although the EPA (1992) estimated that 300,000 pesticide poisoning occurred annually, the National Institute for Occupational Safety and Health states that the total number of pesticide poisonings in the United States is between 10,000–20,000 year^{-1} (NIOSH 2012). Worldwide, the application of 3 million metric tons of pesticides results in more than 26 million cases of non-fatal pesticide poisonings (Richter 2002). Of all the pesticide poisonings, about 3 million cases are hospitalized and there are approximately 220,000 fatalities and about 750,000 chronic illnesses every year (Hart and Pimentel 2002).

2.2.2 Cancer and Other Chronic Effects

Ample evidence exists concerning the carcinogenic threat related to the use of pesticides. The major types of chronic health effects of pesticides include neurological effects, respiratory and reproductive effects, and cancer. There is some evidence that pesticides can cause sensory disturbances as well as cognitive effects such as memory loss, language problems, and learning impairment (Hart and Pimentel 2002). The malady, organophosphate-induced delayed poly-neuropathy (OPIDP), is well documented and includes irreversible neurological damage. In addition to neurological effects, pesticides can have adverse effects on the respiratory and reproductive systems. For example, 15 % of a group of professional pesticide applicators suffered asthma, chronic sinusitis, and/or chronic bronchitis (Weiner and Worth 1969). Studies have also linked pesticides with reproductive effects. For example, some pesticides have been found to cause testicular dysfunction or sterility (Colborn et al. 1997). Sperm counts in males in Europe and the United States, for example, declined by about 50 % between 1938 and 1990 (Carlsen et al. 1992).

US data indicate that 18 % of all insecticides and 90 % of all fungicides are carcinogenic (National Research Council et al. 1987). Several studies have shown that the risks of certain types of cancers are higher in some people, such as farm workers and pesticide applicators, who are often exposed to pesticides, see Table 2.1 (Pimentel and Hart 2001). Certain pesticides have been shown to induce tumors in laboratory animals and there is some evidence that suggest similar effects occur in humans (Colborn et al. 1997).

The United Farm Workers of America and others of the cancer registry in California analyzed the incidence of cancer among Latino farm workers and reported that per year, if everyone in the USA had a similar rate of incidence, there would be 83,000 cases of cancer associated with pesticides in the USA (PAN—North America 2002). The incidence of cancer in the US population due to pesticides ranges from about 10,000 to 15,000 cases year^{-1} (Pimentel et al. 1997).

Table 2.1 Estimated economic costs of human pesticide poisonings and other pesticide-related illnesses in the United States each year

Human health effects from pesticides	Total costs ($)
Cost of hospitalized poisonings	30,000,000
5000[a] × 3 days at $2000 per day	
Cost of outpatient-treated poisonings	30,000,000
30,000[b] × $1000[c]	
Lost work due to poisonings	2,000,000
5000 workers × 5 days × $80	
Pesticide cancers	1,000,000,000
10,000[b] $100,000/case	
Cost of fatalities	166,500,000
45 accidental fatalities[a] × $3.7 million	
Total	1,228,500,000

[a] Estimated.

[b] See text for details

[c] Includes hospitalization, foregone earnings, and transportation

Many pesticides are also estrogenic—they mimic or interact with the hormone estrogen—linking them to an increase in breast cancer among some women. The breast cancer rate rose from 1 in 20 in 1960 to 1 in 8 in 1995 (Colborn et al. 1997). As expected, there was a significant increase in pesticide use during that time period. Pesticides that interfere with the body's endocrine–hormonal system can also have reproductive, immunological, or developmental effects (McCarthy 1993). While endocrine-disrupting pesticides may appear less dangerous because hormonal effects rarely result in acute poisonings, their effects on reproduction and development may prove to have far-reaching consequences (Colborn et al. 1997).

The negative health effects of pesticides can be far more significant in children than adults, for several reasons. First, children have higher metabolic rates than adults, and their ability to activate, detoxify, and excrete toxic pesticides differs from adults. Also, children consume more food than adults and thus can consume more pesticides per unit weight than adults. This problem is particularly significant for children because their brains are more than five times larger in proportion to their body weight than adult brains, making cholinesterase even more vital. In a California study, 40 % of the children working in agricultural fields had blood cholinesterase levels below normal, a strong indication of organophosphate and carbamate pesticide poisoning (Repetto and Baliga 1996). According to the EPA, fetuses where the mother is exposed and toddlers under two years of age are 10 times more at risk for cancer than adults and children from 3 to 15 may have at least three times the cancer risk than adults (USA Today 2003).

Although no one can place a precise monetary value on a human life, the economic "costs" of human pesticide poisonings have been estimated (Table 2.1). For our assessment, we use the EPA standard of $3.7 million per human life (Kaiser 2003). Available estimates suggest that human pesticide poisonings and related illnesses in the United States cost about $1 billion year^{-1} (Pimentel and Greiner 1997).

2.2.3 Pesticide Residues in Food

The majority of foods purchased in supermarkets have detectable levels of pesticide residues. For instance, of several thousand samples of food, the overall assessment in 8 fruits and 12 vegetables is that 73 % have pesticide residues (Baker et al. 2002). In five crops (apples, peaches, pears, strawberries, and celery) pesticide residues were found in 90 % of the crops. A study by Groth et al. (1999) detected 37 different pesticides in apples.

Up to 5 % of the foods tested in 1997 contained pesticide residues that were above the FDA tolerance levels. These foods were consumed even though they violated the US tolerance of pesticide residues in foods because the food samples were analyzed after the foods were sold in the supermarkets (Pesticides Residues Committee—UK 2004).

2.3 Domestic Animal Poisonings and Contaminated Products

In addition to pesticide problems that affect humans, several thousand domestic animals are accidentally poisoned by pesticides each year, with dogs and cats representing the largest number (Table 2.2). For example, of 250,000 poison cases involving animals, a large percentage of the cases were pesticide poisonings (Pimentel and Pimentel 2008). Poisonings of dogs and cats are common which is not surprising because dogs and cats usually wander freely about the home and farm and therefore have greater opportunity to come into contact with pesticides than other domesticated animals.

The best estimates indicate that about 20 % of the total monetary value of animal production, or about $4.2 billion, is lost to all animal illnesses, including pesticide poisonings. It is reported that 0.5 % of animal illnesses and 0.04 % of all animal deaths reported to a veterinary diagnostic laboratory were due to pesticide toxicosis. Thus, $21.3 and $8.8 million, respectively, are lost to pesticide poisonings (Table 2.2).

This estimate is considered low because it is based only on poisonings reported to veterinarians. Many animal deaths that occur in the home and on farms go undiagnosed and unreported. In addition, many are attributed to other factors than pesticides. When a farm animal poisoning occurs and little can be done for the animal, the farmer seldom calls a veterinarian but, rather either waits for the animal to recover or destroys it. Such cases are usually unreported.

Additional economic losses occur when meat, milk, and eggs are contaminated with pesticides. In the United States, all animals slaughtered for human consumption, if shipped interstate, and all imported meat and poultry, must be inspected by the USDA. This is to ensure that the meat and poultry products are wholesome, properly labeled, and do not present a health hazard.

Table 2.2 Estimated domestic animal pesticide poisonings in the United States

Livestock	Number × 1000	$ per head × 1000	Number ill[a] × 1000	$ cost per poisoning[b]	$ cost of poisonings × 1000	Number deaths[c] × 1000	$ cost of deaths[d] × 1000	Total $ × 1000
Cattle	99,000[e]	607[e]	100	121.40	12,140	8	4,856	16,996
Dairy Cattle	10,000[e]	900[e]	10	180.00	1,800	1	900	2,700
Dogs	55,000[f]	125[g]	55	25.00	1,375	4	500	1,875
Horses	11,000[h]	1,000[f]	11	200.00	2,200	1	1,000	3,200
Cats	63,000[f]	207	60	4.00	240	4	80	320
Swine	53,000[e]	66.3[e]	53	13.26	703	4	265	968
Chickens	8×10^{6}[e,f]	2.5[e]	6000	0.40	2,400	500	1,250	3,650
Turkeys	2.8×10^{5}[e]	106	280	2.00	560	25	250	810
Sheep	11,000[e]	82.40[e]	11	16.48	181	1	82.2	63
Total	8.582×10^{6}[f]				21,599			30,582

[a] Based on a 0.1 % illness rate (see text)
[b] Based on each animal illness costing 20 % of total production value of that animal
[c] Based on a 0.008 % mortality rate (see text)
[d] The death of the animal equals the total value for that animal
[e] USDA (1989)
[f] USBC (1990)
[g] Estimated
[h] FAO (1986)

Pesticide residues are searched for in animals and their products. However, of more than 600 pesticides in use now, the National Residue Program (USDA, Office of Inspector General 2010) only searches for about 40 different pesticides, which have been determined by FDA, EPA, and FSIS to be of public health concern. While the monitoring program records the number and type of violations, there might be little cost to the animal industry because the meat and other products are sometimes sold and consumed by the public before the test results are available. For example, about 3 % of chickens with illegal pesticide residues are sold in the market (National Research Council et al. 1987).

In addition to animal carcasses, pesticide-contaminated milk cannot be sold and must be disposed of. In some instances, these losses are substantial. In Oahu, Hawaii in 1982, 80 % of the milk supply, worth more than $8.5 million, was condemned by the public health officials because it had been contaminated with the insecticide heptachlor (Baker et al. 2002). This incident had immediate and far-reaching effects on the entire milk industry on the island.

2.4 Destruction of Beneficial Natural Predators and Parasites

In both natural and agricultural ecosystems, many species, especially predators and parasites, control or help control plant-feeding arthropod populations. Indeed, these natural beneficial species make it possible for ecosystems to remain "green."

With the parasites and predators keeping plant-feeding arthropod populations at low levels, only a relatively small amount of plant biomass is removed each growing season by arthropods (Hairston et al. 1960; Pimentel 1988). Like pest populations, beneficial natural enemies and biodiversity (predators and parasites) are adversely affected by pesticides (Pimentel et al. 1993a). The following pests have reached outbreak levels in cotton and apple crops after the natural enemies were destroyed by pesticides:

- cotton—cotton bollworm, tobacco budworm, cotton aphid, spider mites, and cotton loopers;
- apples—European red mite, red-banded leaf roller, San Jose scale, oyster shell scale, rosy apple aphid, wooly apple aphid, white apple aphid, two-spotted spider mite, and apple rust mite (Pimentel et al. 1993a)

Major pest outbreaks have also occurred in other crops due to the destruction of natural enemies. Also, because parasitic and predaceous insects often have complex searching and attack behaviors, sub-lethal insecticide dosages may alter this searching and attack behavior and in this way disrupt effective biological controls (Pimentel et al. 1993a).

Fungicides also can contribute to pest outbreaks when they reduce fungal pathogens that are naturally parasitic on many insects. For example, the use of benomyl reduces populations of entomopathogenic fungi, resulting in increased survival of velvet bean caterpillars and cabbage loopers in soybeans. This eventually leads to reduced soybean yields (Pimentel et al. 1993a).

When outbreaks of secondary pests occur because their natural enemies are destroyed by pesticides, additional and sometimes more expensive pesticide treatments have to be made in efforts to sustain crop yields. This raises the overall costs and contributes to pesticide-related problems. An estimated $520 million can be attributed to costs of additional pesticide application and increased crop losses, both of which follow the destruction of natural enemies by various pesticides applied to crops (Table 2.3).

Natural enemies are being adversely affected by pesticides worldwide. Although no reliable estimate is available concerning the impact of this in terms of increased pesticide use and/or reduced crop yields, entomologists often observe a severe impact due to the loss of natural enemies where pesticides are heavily used in many parts of the world. From 1980 to 1985 insecticide use in rice production in Indonesia drastically increased (Oka 1991) which caused the destruction of beneficial natural enemies of the brown plant hopper and causing the brown plant hopper population to explode. Rice yield decreased to the extent that rice had to be imported to Indonesia. The estimated cost of rice loss in just a 2-year period was $1.5 billion (Soejitno 1999).

After this incident, Dr. I.N. Oka, who had previously developed a successful low-insecticide program for rice pests in Indonesia, was consulted by the Indonesian President Suharto's staff to determine what should be done to rectify the situation. Oka's advice was to substantially reduce insecticide use and return to a sound "treat-when-necessary" program that protected the natural enemies. Following Oka's advice, President Suharto mandated in 1986 on television that 57 of

Table 2.3 Losses due to the destruction of beneficial natural enemies in US crops ($ millions)

Crops	Total expenditures for insect control with pesticides[a]	Amount of added control costs
Cotton	320	160
Tobacco	5	1
Potatoes	31	8
Peanuts	18	2
Tomatoes	11	2
Onions	1	0.2
Apples	43	11
Cherries	2	1
Peaches	12	2
Grapes	3	1
Oranges	8	2
Grapefruit	5	1
Lemons	1	0.2
Nuts	160	16
Other	500	50
Total ($)	1,120	257.4 (520)[b]

[a] Pimentel et al. (1991)

[b] Because the added pesticide treatments do not provide as effective control as the natural enemies, we estimate that at least an additional $260 million in crops are lost to pests. Thus the total loss due to the destruction of natural enemies is estimated to be at least $520 million year^{-1}

64 pesticides would be withdrawn from use on rice, and sound pest management practices implemented. Pesticide subsidies were also reduced to zero. By 1991, pesticide applications had been reduced by 65% and rice yields increased by 12%.

Dr. David Rosen (Hebrew University of Jerusalem, PC, 1991) estimates that natural enemies account for up to 90% of the control of pest species in agroecosystems. I estimate that at least 50% of the control of pest species is due to natural enemies. Pesticides provide an additional control, while the remaining 40% is due to host–plant resistance in agroecosystems (Pimentel 1988).

Parasites, predators, and host–plant resistance are estimated to account for about 80% of the nonchemical control of pest arthropods and plant pathogens in crops (Pimentel et al. 1991). Many cultural controls including crop rotations, soil and water management, fertilizer management, planting time, crop-plant density, trap crops, and polyculture provide additional pest control. Together these non-pesticide controls can be used to effectively reduce US pesticide use by more than 50% without any reduction in crop yields or cosmetic standards (Pimentel et al. 1993a).

2.5 Pesticide Resistance in Pests

In addition to destroying natural enemy populations, the extensive use of pesticides has often resulted in the development and evolution of pesticide resistance in insect pests, plant pathogens, and weeds. An early report by the United Nations Environmental Program (UNEP 1979) suggested that pesticide resistance ranked as one of the top 4 environmental problems of the world. About 520 insect and mite species, nearly 150 plant pathogen species, and about 273 weeds species are now resistant to pesticides (Stuart 1999).

Increased pesticide resistance in pest populations frequently results in the need for several additional applications of the commonly used pesticides to maintain crop yields. These additional pesticide applications compound the pesticide resistance problem by increasing environmental selection of pest populations for resistance. The pesticide resistance problem continues to increase despite all efforts and is spreading to other pest species. Over time extremely high pesticide resistance had developed in the tobacco budworm population on cotton in northeastern Mexico and the Lower Rio Grande of Texas (NAS 1975). Finally approximately 285 000 ha of cotton had to be abandoned, because the insecticides used were totally ineffective due to extreme resistance in the budworm. The economic and social impact on these Texan and Mexican farmers dependent on cotton was devastating. The study by Carrasco-Tauber (1989) reported a yearly loss of \$45– \$120 ha^{-1} to pesticide resistance in California cotton. A total of 4.2 million hectares of cotton were harvested in 1984; thus, assuming a loss of \$82.50 ha^{-1}, approximately \$348 million of the California cotton crop was lost due to pesticide resistance. Since \$3.6 billion of US cotton was harvested in 1984 (USBC 1990), the loss due to resistance for that year was approximately 10 %. Assuming a 10 % loss in other major crops that receive heavy pesticide treatments in the United States, crop losses due to pesticide resistance are estimated to be about \$1.5 billion year^{-1}.

Efforts to control resistant *Heliothus* spp. (corn ear worm) exact a cost on other crops when large, uncontrolled populations of *Heliothus* and other pests disperse onto other crops. In addition, the cotton aphid and the whitefly populations exploded as secondary cotton pests because of their pesticide resistance and their natural enemies' exposure to high concentrations of insecticides (Pimentel et al. 1993a).

The total external cost attributed to the development of pesticide resistance is estimated to range between 10 and 25 % of current pesticide treatment costs (Harper and Zilberman 1990), or more than \$1.5 billion each year in the United States. In other words, at least 10 % of pesticide used in the USA is applied just to combat increased resistance that has developed in several pest species.

Although the costs of pesticide resistance are high in the United States, the costs in tropical developing countries are significantly greater, because pesticides are not only used to control agricultural pests, but also vital for the control of arthropod disease vectors. One of the major costs of resistance in tropical countries is associated with malaria control. By 1985, the incidence of malaria in India after early pesticide use declined to about 1.86 million cases from a peak of 70 million cases. However, because mosquitoes developed resistance to pesticides, as did malarial parasites to drugs, the incidence of malaria in India has now ranges between 1.5–2.0 million cases year^{-1} (Reid 2000; Kakkilaya 2012). Problems are occurring not only in India but also in the rest of Asia, Africa, and South America. The total number of people at risk of malaria in 2010 in the world is now 3.3 billion (WHO 2011).

2.6 Honeybee and Wild Bee Poisonings and Reduced Pollination

Honeybees and wild bees are vital for pollination of fruits, vegetables, and other crops. Bees are essential to the production of about one-third of US and world crops. Their benefits to US agriculture are estimated to be about \$40 billion year^{-1} (Pimentel et al. 1997). Because most insecticides used in agriculture are toxic to bees, pesticides have a major impact on both honeybee and wild bee populations. D. F. Mayer (Washington State University, PC, 1990) estimates that approximately 20 % of all honeybee colonies are adversely affected by pesticides. He includes the approximately 5 % of US honeybee colonies that are killed outright or die during winter because of pesticide exposure. Mayer calculates that the direct annual loss reaches \$13.3 million year^{-1} (Table 2.4). Another 15 % of the honeybee colonies are either seriously weakened by pesticides or suffer losses when apiculturists have to move colonies to avoid pesticide damage. According to Mayer, the yearly estimated loss from partial honeybee kills, reduced honey production, plus the cost of moving colonies totals about \$25.3 million year^{-1}. Also, as a result of heavy pesticide use on certain crops, beekeepers are excluded from 4 to 6 million ha of otherwise suitable apiary locations, according to Mayer. He estimates the yearly loss in potential honey production in these regions is about \$27 million (Table 2.4).

In addition to these direct losses caused by the damage to honeybees and honey production, many crops are lost because of the lack of pollination. In California, for example, approximately 1 million colonies of honeybees are rented annually at \$55 per colony to augment the natural pollination of almonds, alfalfa, melons, and other fruits and vegetables (Burgett 2001). Since California produces nearly half of our bee-pollinated crops, the total cost for honeybee rental for the entire country is estimated at \$40 million year^{-1}. Of this cost, I estimate that at least one-tenth or \$4 million is attributed to the effects of pesticides (Table 2.4). Estimates of annual agricultural losses due to the reduction in pollination caused by pesticides may be as high as \$4 billion year^{-1} (J. Lockwood, University of Wyoming, PC, 1990). For most crops, both yield and quality are enhanced by effective pollination. Several investigators have demonstrated that for various cotton varieties, effective pollination by honeybees resulted in yield increases of from 20 to 30 %.

Mussen (1990) emphasizes that poor pollination will not only reduce crop yields, but also equally important, it will reduce the quality of some crops, such as melons and fruits. In experiments with melons, E.L. Atkins (University of California at Davis, PC, 1990) reported that with adequate pollination melon yields increased 10 % and melon quality was raised 25 % as measured by the dollar value of the melon crop.

Based on the analysis of honeybee and related pollination losses from wild bees caused by pesticides, pollination losses attributed to pesticides are estimated to represent about 10 % of pollinated crops and have a cost of about \$210 million year^{-1} (Table 2.4). Clearly, the available evidence confirms that the yearly cost of direct

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