Chapter 4
Environmental and Economic Costs of the Application of Pesticides Primarily in the United States

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Abstract An obvious need for an update and comprehensive study prompted this investigation of the complex environmental costs resulting from the nation's dependence on pesticides. Included in this assessment of an estimated $12 billion in environmental and societal damages are analysis of pesticide impacts on public health; livestock and livestock product losses; increased control expenses resulting from pesticide-related destruction of natural enemies and from 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-1; pesticide resistance in pests, $1.5 billion; crop losses caused by pesticides, $1.1 billion; bird losses due to pesticides, $2.2 billion; and ground water contamination, $2.0 billion.

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

4.1 Introduction

Worldwide, about 3 billion kg of pesticides are applied each year with a purchase price of nearly $40 billion per year (Pan-UK, 2003). In the U.S., approximately 500 million kg of more than 600 different pesticide types are applied annually at a cost of $10 billion (Pimentel and Greiner, 1997).

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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. For example, 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 nearly resulted in an increase in corn losses to insects from about 3.5% to 12% despite a more than 1,000-fold increase in insecticide (organophosphate) use in corn production (Pimentel et al., 1991). Corn today 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 environment and economic costs associated with the recommended application of pesticides in crops. To facilitate the development and implementation of a scientifically sound policy of pesticide use, these environmental and economic costs must be examined. For several decades, the U.S. 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.

4.2 Public Health Effects

4.2.1 Acute Poisonings

Human pesticide poisonings and illnesses are clearly the highest price paid for all pesticide use. The total number of pesticide poisonings in the United States is estimated to be 300,000 per year (EPA, 1992). 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).

4.2.2 Cancer and Other Chronic Effects

Ample evidence exists concerning the carcinogenic threat related to the use of pesticides. These 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, 1972). Studies have also linked pesticides with reproductive effects. For example, some pesticides have been found to cause testicular dysfunction or sterility (Colborn et al., 1996). Sperm counts in males in Europe and the United States, for example, declined by about 50% between 1938 and 1990 (Carlsen et al., 1992). Currently, there is evidence that human sperm counts continue to decrease by about 2% per year (Pimentel and Hart, 2001).

The U.S. data indicate that 18% of all insecticides and 90% of all fungicides are carcinogenic (NAS, 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 (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., 1996).

A UFW (2003) study of the cancer registry in California analyzed the incidence of cancer among Latino farm workers and reported that per year, if everyone in the U.S. had a similar rate of incidence, there would be 83,000 cases of cancer associated with pesticides in the U.S. The incidence of cancer in the U.S. population due to pesticides ranges from about 10,000 to 15,000 cases per year (Pimentel et al., 1997).

Many pesticides are also estrogenic – they mimic or interact with the hormone estrogen – linking them to 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., 1996). 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., 1996).

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 5 times larger in proportion to their body weight than adult brains, making chloinesterase 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, babies and toddlers are 10 times more at risk for cancer than adults (Hebert, 2003).

Table 4.1 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	
5000[a] × 3 days @ $2,000/day	30,000,000
Cost of outpatient treated poisonings	
30,000[c] × $1,000[b]	30,000,000
Lost work due to poisonings	
5,000[a] workers × 5 days × $80	2,000,000
Pesticide cancers	
10,000[c] × $100,000/case	1,000,000,000
Cost of fatalities	
45 accidental fatalities[a] × $3.7 million	166,500,000
Total	1,228,500,000

[a] Estimated.
[b] Includes hospitalization, foregone earnings, and transportation.
[c] See text for details.

Although no one can place a precise monetary value on a human life, the economic "costs" of human pesticide poisonings have been estimated (Table 4.1). 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 per year (Pimentel and Greiner, 1997).

4.2.3 Pesticide Residues in Food

The majority of foods purchased in super markets have detectable levels of pesticide residues. For instance, of several thousand samples of food, the overall the assessment in 8 fruits and 12 vegetables is that 73% have pesticide residues (Baker et al., 2003). In 5 crops (apples, peaches, pears, strawberries and celery) pesticide residues were found in 90% of the crops. Of interest is the fact that 37 different pesticides were detected in apples (Groth et al., 1999).

Up to 5% of the foods tested in 1997 contained pesticide residues that were above the FDA tolerance levels. Although these foods violated the U.S. tolerance of pesticide residues in foods, these same foods were consumed by the public. This is because the food samples were analyzed after the foods were sold in the super markets.

4.3 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 4.2). For example, of 250,000 poison cases involving

Table 4.2 Estimated domestic animal pesticide poisonings in the United States

Livestock	Number × 1000	$ per head	Number ill[e]	$ cost per poisoning[f]	$ cost of poisonings	Number deaths[d]	$ cost of deaths × 1,000[g]	Total$ × 1,000
Cattle	99,000[a]	607[a]	100	121.40	12,140	8	4,856	16,996
Dairy cattle	10,000[a]	900[a]	10	180.00	1,800	1	900	2,700
Dogs	55,000[c]	125[h]	55	25.00	1,375	4	500	1,875
Horses	11,000[b]	1,000[c]	11	200.00	2,200	1	1,000	3,200
Cats	63,000[c]	20[h]	60	4.00	240	4	80	320
Swine	53,000[a]	66.30[a]	53	13.26	703	4	265	968
Chickens	8,000,000[a]	2.50[a]	6000	.40	2,400	500	1,250	3,650
Turkeys	280,000[a]	10[c]	280	2.00	560	25	250	810
Sheep	11,000[a]	82.40[a]	11	16.48	181	1	82	263
Total	8,582,000				21,599			30,782

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

animals, a large percentage of the cases were related to pesticides (National Animal Poison Control Centers, 2003). Poisonings of dogs and cats are common. This 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 4.2).

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. Also, 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 pesticide. 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 insure that the meat and products are wholesome, properly labeled, and do not present a health hazard.

Pesticide residues are searched for in animals and their products. However, of the more than 600 pesticides in use now, the National Residue Program (NRP) 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 the chicken with illegal pesticide residues are sold in the market (NAS, 1987).

In addition to animal carcasses, pesticide-contaminated milk cannot be sold and must be disposed of. In some instances, these losses are substantial. For example, 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., 2003). This incident had immediate and far-reaching effects on the entire milk industry on the island.

4.4 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 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). For example, 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 leafroller, San Jose scale, oyster shell scale, rosy apple aphid, wooly apple aphid, white apple aphid, two-spotted spider mite, and apple rust mite. Major pest outbreaks have also occurred in other crops. Also, because parasitic and predaceous insects often have complex searching and attack behaviors, sub-lethal insecticide dosages may alter this behavior and in this way disrupt effective biological controls.

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.

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.

Table 4.3 Losses due to the destruction of beneficial natural enemies in U.S. 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 per year.

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 4.3).

As in the United States, 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, general observations by entomologists indicate that the impact of loss of natural enemies is severe where pesticides are heavily used in many parts of the world. For example, from 1980 to 1985 insecticide use in rice production in Indonesia drastically increased (Oka, 1991). This caused the destruction of beneficial natural enemies of the brown planthopper and this pest population exploded. Rice yield decreased to the extent that rice had to be imported into Indonesia. The estimated cost of rice loss in just a 2-year period was $1.5 billion (FAO, 1988).

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 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 12%.

Dr. Rosen (Hebrew University of Jerusalem, PC. 1991) estimates that natural enemies account for up to 90% of the control of pests 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, such as crop rotations, soil and water management, fertilizer management, planting time, crop-plant density, trap crops, polyculture, and others provide additional pest control. Together these non-pesticide controls can be used to effectively reduce U.S. pesticide use by more than 50% without any reduction in crop yields or cosmetic standards (Pimentel et al., 1993a).

4.5 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, a total of nearly 150 plant pathogen species, and about 273 weeds species are now resistant to pesticides (Stuart, 2003).

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 problem by increasing environmental selection for resistance. Despite efforts to deal with the pesticide resistance problem, it continues to increase and spread to other species. A striking example of pesticide resistance occurred in northeastern Mexico and the Lower Rio Grande of Texas (NAS, 1975). Over time extremely high pesticide resistance had developed in the tobacco budworm population on cotton. Finally approximately 285,000 ha of cotton had to be abandoned, because the insecticides were totally ineffective because of the 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) indicates the extent of costs associated with pesticide resistance. They reported a yearly loss of $45 to $120 per ha 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 per hectare, approximately $348 million of the California cotton crop was lost to resistance. Since $3.6 billion of U.S. 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 per year.

Furthermore, 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 exploded as secondary cotton pests because of their resistance and their natural enemies' exposure to high concentrations of insecticides.

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 U.S. 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 are 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 2 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 exploded to about 60 million cases per year (Malaria, 2000). Problems are occurring not only in India but also in the rest of Asia, Africa, and South America. The total number of malaria cases in the world is now 2.4 billion (WHO, 1997).

4.6 Honeybee and Wild Bee Poisonings and Reduced Pollination

Honeybees and wild bees are vital for pollination of fruits, vegetable, and other crops. Bees are essential to the production of about one-third of U.S. and world crops. Their benefits to U.S. agriculture are estimated to be about $40 billion per year (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. 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 U.S. 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 per year (Table 4.4). Another 15% of the honeybee colonies either are 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 per year. 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 each year (Table 4.4).

Table 4.4 Estimated honeybee losses and pollination losses from honeybees and wild bees

Colony losses from pesticides	$13.3 million/year
Honey and wax losses	$25.3 million/year
Loss of potential honey production	$27.0 million/year
Bee rental for pollination	$ 8.0 million/year
Pollination losses	$210.0 million/year
Total	$283.6 million/year

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, 2000). 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 per year. Of this cost, I estimate that at least one-tenth or $4 million is attributed to the effects of pesticides (Table 4.4).

Estimates of annual agricultural losses due to the reduction in pollination caused by pesticides may be as high as $4 billion per year (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 from 20% to 30%.

Mussen (1990) emphasizes that poor pollination will not only reduce crop yields, but equally important, it will reduce the quality of some crops, such as melon and fruits. In experiments with melons, E.L. Atkins (University of California [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 yearly cost of about $210 million per year (Table 4.4). Clearly, the available evidence confirms that the yearly cost of direct honeybee losses, together with reduced yields resulting from poor pollination, are significant.

4.7 Crop and Crop Product Losses

Basically, pesticides are applied to protect crops from pests in order to increase yields, but sometimes the crops are damaged by the pesticide treatments. This occurs when (1) the recommended dosages suppress crop growth, development, and yield; (2) pesticides drift from the targeted crop to damage adjacent crops; (3) residual herbicides either prevent chemical-sensitive crops from being planted; and/or (4) excessive pesticide residue accumulates on crops, necessitating the destruction of the harvest. Crop losses translate into financial losses for growers, distributors, wholesalers, transporters, retailers, food processors, and others. Potential profits as well as investments are lost. The costs of crop losses increase when the related costs of investigations, regulation, insurance, and litigation are added to the equation. Ultimately the consumer pays for these losses in higher market place prices.

Data on crop losses due to pesticides are difficult to obtain. Many losses are never reported to the state and federal agencies because the parties settle privately (Pimentel et al., 1993a).

Damage to crops may occur even when recommended dosages of herbicides and insecticides are applied to crops under normal environmental conditions. Recommended dosages of insecticides used on crops have been reported to suppress growth and yield in both cotton and strawberry crops (ICAITI, 1977; Reddy et al., 1987; Trumbel et al., 1988). The increase in susceptibility of some crops to insects and diseases following normal use of 2,4-D and other herbicides has been demonstrated (Oka and Pimentel, 1976; Pimentel, 1994). Furthermore, when weather and/or soil conditions are inappropriate for pesticide application, herbicide treatments may cause yield reductions ranging from 2% to 50% (Pimentel et al., 1993a).

Crops are lost when pesticides drift from the target crops to non-target crops located as much as several miles downwind (Barnes et al., 1987). Drift occurs with most methods of pesticide application including both ground and aerial equipment; the potential problem is greatest when pesticides are applied by aircraft. With aircraft from 50% to 75% of the pesticide applied never reaches the target acre (Akesson and Yates, 1984; Mazariegos, 1985; Pimentel et al., 1993a). In contrast, 10% to 35% of the pesticide applied with ground application equipment misses the target area (Hall, 1991). The most serious drift problems are caused by “speed sprayers” and ultra low volume (ULV) equipment, because relatively concentrated pesticide is applied. The concentrated pesticide has to be broken into small droplets to achieve adequate coverage.

Crop injury and subsequent loss due to drift are particularly common in areas planted with diverse crops. For example, in southwest Texas in 1983 and 1984, nearly $20 million in cotton was destroyed from drifting 2,4-D herbicide when adjacent wheat fields were aerially sprayed with the herbicide (Hanner, 1984). Because of the drift problem, most commercial applicators carry insurance that costs about $245 million per year (Pimentel et al., 1993a; Table 4.5).

Table 4.5 Estimated loss of crops and trees due to the use of pesticides

Impacts	Total costs (in millions of dollars)
Crop losses	136
Crop applicator insurance	245
Crops destroyed because of excess Pesticide contamination	1,000
Governmental investigations and testing	10
Total	$1,391

When residues of some herbicides persist in the soil, crops planted in rotation are sometimes injured. This has happened with a corn and soybean rotation. When atrazine or Sceptor herbicides were used in corn, the soybean crop planted after was seriously damaged by the herbicides that persist in the soil. This problem also has environmental problems associated. For example, if the herbicide treatment prevents another crop from being grown, soil erosion may be intensified (Pimentel et al., 1993a).

An average 0.1% loss in annual U.S. production of corn, soybeans, cotton, and wheat, which together account for about 90% of the herbicides and insecticides used in U.S. agriculture, was valued at $35.3 million in 1987 (NAS, 1989). Assuming that only one-third of the incidents involving crop losses due to pesticides are reported to authorities, the total value of all crop lost because of pesticides could be as high as 3 times this amount, or $106 million annually.

However, this $106 million does not take into account other crop losses, nor does it include major events such as the large-scale losses that have occurred in one season in Iowa ($25 to $30 million), in Texas ($20 million), and in California's aldicarb/watermelon crisis ($8 million) (Pimentel et al., 1993a). These recurrent losses alone represent an average of $30 million per year, raising the estimated average crop loss value from the use of pesticides to approximately $136 million each year.

Additional losses are incurred when food crops are disposed of because they exceed the FDA and EPA regulatory tolerances for pesticide residue levels. Assuming that all the crops and crop products that exceed the FDA and EPA regulatory tolerances (reported to be 1% to 5%) were disposed of as required by law, then about $1 billion in crops would be destroyed because of excessive pesticide contamination.

Special investigations and testing for pesticide contamination are estimated to cost the nation more than $10 million each year (Pimentel et al., 1993a).

4.8 Ground and Surface Water Contamination

Certain pesticides applied at recommended dosages to crops eventually end up in ground and surface waters. The 3 most common pesticides found in groundwater are aldicarb, alachlor, and atrazine (Cornell, 2003). Estimates are that nearly one-half of the groundwater and well water in the United States is or has the potential to be contaminated (Holmes et al., 1988; USGS, 1996). EPA (1990) reported that 10% of community wells and 4% of rural domestic wells have detectable levels of at least one pesticide of the 127 pesticides tested in a national survey. Estimated costs to sample and monitor well and groundwater for pesticide residues costs $1,100 per well per year (USGS, 1995). With 16 million wells in the U.S., the cost of monitoring all the wells for pesticides would cost $17.7 billion per year (Well-Owner, 2003).

Two major concerns about ground water contamination with pesticides are that about one-half the human population obtains its water from wells and once groundwater is contaminated, the pesticide residues remain for long periods of time. Not only are there extremely few microbes present in groundwater to degrade the pesticides, but the groundwater recharge rate is less than 1% per year (CEQ, 1980).

Monitoring pesticides in groundwater is only a portion of the total cost of groundwater contamination. There is also the high cost of cleanup. For instance, at the Rocky Mountain Arsenal near Denver, Colorado, the removal of pesticides from the groundwater and soil was estimated to cost approximately $2 billion. If all pesticide-contaminated groundwater were to be cleared of pesticides before human consumption, the cost would be about $500 million per year. Note the cleanup process requires a water survey to target the contaminated water for cleanup. Thus, addition the monitoring and cleaning costs, the total cost regarding pesticide-polluted groundwater is estimated to be about $2 billion annually. The $17.7 billion figure shows how impossible it would be to expect the public to pay for pesticide-free well water.

4.9 Fishery Losses

Pesticides are washed into aquatic ecosystems by water runoff and soil erosion. About 13 t/ha/yr are washed and/or blown from pesticide-treated cropland into adjacent locations including rivers and lakes (Unnevehr et al., 2003). Pesticides also can drift during application and contaminate aquatic systems. Some soluble pesticides are easily leached into streams and lakes.

Once in aquatic ecosystems, pesticides cause fishery losses in several ways. These include high pesticide concentrations in water that directly kill fish; low doses that may kill highly susceptible fish fry; or the elimination of essential fish foods, like insects and other invertebrates. In addition, because government safety restrictions ban the catching or sale of fish contaminated with pesticide residues, such fish are unmarketable and are an economic loss.

Only 6 to 14 million fish are reported killed by pesticides each year (Pimentel et al., 1993a). However, this is an underestimate because fish kills cannot be investigated quickly enough to determine accurately the cause of the kill. Also, if the fish are in fast-moving waters in rivers, the pesticides are diluted and/or the pesticides cannot be identified. Many fish sink to the bottom and cannot be counted.

The best estimate for the value of a fish is $10. This is based on EPA fining Coors Beer $10 per fish when they polluted a river (Barometer, 1991). Thus, the estimate of the value of fish killed each year is only $10 to $24 million per year. This is an under estimate and I estimate $100 million per year minimum.

4.10 Wild Birds and Mammals

Wild birds and mammals are damaged and destroyed by pesticides and these animals make excellent “indicator species”. Deleterious effects on wildlife include death from the direct exposure to pesticides or secondary poisonings from consuming contaminated food; reduced survival, growth, and reproductive rates from exposure to sub-lethal dosages; and habitat reduction through the elimination of food resources and refuges. In the United States, approximately 3 kg of pesticide is applied per hectare on about 160 million hectares of cropland each year (Pimentel et al., 1993a). With such heavy dosages of pesticides applied, it is expected that wildlife would be significantly impacted.

The full extent of bird and mammal kills is difficult to determine because birds and mammals are often secretive, camouflaged, highly mobile, and live in dense grass, shrubs, and trees. Typical field studies of the effects of pesticides often obtain extremely low estimates of bird and mammal mortality (Mineau et al., 1999). This is because bird and small mammal carcasses disappear quickly, well before the dead birds and small mammals can be found and counted. Even when known numbers of bird carcasses were placed in identified locations in the field, from 62% to 92% of the animals disappeared overnight due to vertebrate and invertebrate scavengers (Balcomb, 1986). Then in addition, field studies seldom account for birds that die a distance from the treated areas. Finally, birds often hide and die in inconspicuous locations.

Nevertheless, many bird kills caused by pesticides have been reported. For instance, 1,200 Canada geese were killed in one wheat field that was sprayed with a 2:1 mixture of parathion and methyl parathion at a rate of 0.8 kg/ha (White et al., 1982). Carbofuran applied to alfalfa killed more than 5,000 ducks and geese in five incidents, while the same chemical applied to vegetable crops killed 1,400 ducks in a single application (Flickinger et al., 1980, 1991). Carbofuran is estimated to kill 1 to 2 million birds each year (EPA, 1989). Another pesticide, diazinon, applied to three golf courses killed 700 Atlantic brant geese of the wintering population of just 2,500 birds (Stone and Gradoni, 1985).

EPA reports that there are 1100 documented cases of bird kills each year in the United States (ABCBirds, 2003). Birds are not only killed in the U.S. but they are killed as they migrate from North America to South America. For example, more than 4,000 carcasses of Swainson's hawks were reported poisoned by pesticides in late 1995 and early 1996 in farm fields of Argentina (CWS, 2003). Although it was not possible to know the total kill, conservatively it was estimated to be more than 20,000 hawks.

Several studies report that the use of some herbicides has a negative impact on some young birds. Since the weeds would have harbored some insects in the crops, their nearly total elimination by herbicides is devastating to particular bird populations (Potts, 1986; R. Beiswenger, University of Wyoming, PC, 1990). This has led to significant reductions in the grey partridge in the United Kingdom and in the common pheasant in the United States. In the case of the partridge, population levels have decreased more than 77% because the partridge chicks (also pheasant chicks) depend on insects to supply them with needed protein for their development and survival.

Frequently the form of a pesticide influences its toxicity to wildlife (Hardy, 1990). For example, treated seed and insecticide granules, including carbofuran, fensulfothion, fonofos, and phorate, are particularly toxic to birds. Estimates are that from 0.23 to 1.5 birds per hectare were killed in Canada, while in the United States the estimates of kill ranged from 0.25 to 8.9 birds killed per hectare per year by the pesticides (Mineau, 1988). Pesticides also adversely affect the reproductive potential of many birds and mammals. Exposure of birds, especially predatory birds, to chlorinated insecticides has caused reproductive failure, sometimes attributed to eggshell thinning (Elliot et al., 1988). Most the affected predatory birds, like the bald eagle and peregrine falcon, have recovered since the banning of DDT and most other chlorinated insecticides in the U.S. (Unnevehr et al., 2003). Although the U.S. and most other developed countries have banned DDT and other chlorinated insecticides, other countries, such as India and China, are still producing, exporting, and using DDT (Asia Times, 2001).

Habitat alteration and destruction can be expected to reduce mammal and bird populations. For example, when glyphosphate (Roundup) was applied to forest clear cuts to eliminate low-growing vegetation, like shrubs and small trees, the southern red-backed vole population was greatly reduced because its food source and cover were practically eliminated (D'Anieri et al., 1987). Similar effects from herbicides have been reported on other mammals. Overall, the impacts of pesticides on mammal populations have been inadequately investigated.

Although the gross values for wildlife are not available, expenditures involving wildlife made by humans are one measure of the monetary value. Nonconsumptive users of wildlife spent an estimated $14.3 billion on their sport (USFWS, 1988). Yearly, U.S. bird watchers spend an estimated $600 million on their sport and an additional $500 million on birdseed, or a total of $1.1 billion (USFWS, 1988). For bird watching, the estimated cost is about 40¢ per bird. The money spent by hunters to harvest 5 million game birds was $1.1 billion, or approximately $216 per bird (USFWS, 1988). In addition, the estimated cost of replacing a bird of an affected species to the wild, as in the case of the Exxon Valdez oil spill, was $800 per bird (Dobbins, 1986).

If it is assumed that the damages that pesticides inflict on birds occur primarily on the 160 million ha of cropland that receive the most pesticide, and the bird population is estimated to be 4.4 birds per ha of cropland (Boutin et al., 1999), then 720 million birds are directly exposed to pesticides. Also, if it is conservatively estimated that only 10% of the bird population is killed by the pesticide treatments, it follows that the total number of birds killed is 72 million birds. Note this estimate is at the lower range of the range of 0.25 to 8.9 birds killed per hectare per year mentioned earlier.

The American Bald Eagle and other predatory birds suffered high mortalities because of DDT and other chlorinated insecticides. The Bald eagle population declined primarily because of pesticides and was placed on the endangered species list. After DDT and the other chlorinated insecticides were banned in 1972, it took nearly 30 years for the bird populations to recover. The American Bald Eagle was recently removed from the endangered species list (Millar, 1995).

I assumed a value of a bird to be about $30 based on the information presented, plus the fact that the cost of a fish is about $10, even a 1 inch fish. Thus, the total economic impact of pesticides on birds is estimated to be $2.1 billion per year. This estimate does not include the birds killed due to the death of one of the parents and in turn the deaths of the nestlings. It also does not include nestlings killed because they were fed contaminated arthropods and other foods.

4.11 Microbes and Invertebrates

Pesticides easily find their way into soils, where they may be toxic to arthropods, earthworms, fungi, bacteria, and protozoa. Small organisms are vital to ecosystems because they dominate both the structure and function of ecosystems (Pimentel et al., 1992).

For example, an estimated 4.5 tons per hectare of fungi and bacteria exist in the upper 15 cm of soil. They, with the arthropods, make up 95% of all species and 98% of the biomass (excluding vascular plants). The microbes are essential to proper functioning in the ecosystem, because they break down organic matter, enabling the vital chemical elements to be recycled (Atlas and Bartha, 1987; Pimentel et al., 1997). Equally important is their ability to "fix" nitrogen, making it available to plants and ecosystems (Pimentel et al., 1997).

Earthworms and insects aid in bringing new soil to the surface at a rate of up to 200 tons/ha per year (Pimentel et al., 1993a). This action improves soil formation and structure for plant growth and makes various nutrients more available for absorption by plants. The holes (up to 10,000 holes per square meter) in the soil made by earthworms and insects also facilitate the percolation of water into the soil (Edwards and Lofty, 1982).

Insecticides, fungicides, and herbicides reduce species diversity in the soil as well as the total biomass of these biota. Stringer and Lyons (1974) reported that where earthworms had been killed by pesticides, the leaves of apple trees accumulated on the surface of the soil and increased the incidence of scab in the orchards. Apple scab, a disease carried over from season to season on fallen leaves, is commonly treated with fungicides. Some fungicides, insecticides, and herbicides are toxic to earthworms, which would otherwise remove and recycle the fallen leaves.

On golf courses and other lawns, the destruction of earthworms by pesticides results in the accumulation of dead grass or thatch in the turf (Potter and Braman, 1991). To remove this thatch special equipment must be used and it is expensive.

Although these microbes and invertebrates are essential to the vital structure and function of both natural and agricultural ecosystems, it is impossible to place a money value on the damage caused by pesticides to this large group of organisms. To date, no relevant quantitative data on the value of microbe and invertebrate destruction by pesticides are available.

4.12 Government Funds for Pesticide Pollution Control

A major environmental cost associated with all pesticide use is the cost of carrying out state and federal regulatory actions, as well as pesticide-monitoring programs needed to control pesticide pollution. Specifically, these funds are spent to reduce the hazards of pesticides and to protect the integrity of the environment and public health.

About $10 million is spent each year by state and federal governments to train and register pesticide applicators. Also, more than $60 million is spent each year by the EPA to register and reregister pesticides. In addition, about $400 million is spent to monitor pesticide contamination of fruits, vegetables, grains, meat, milk, water, and other items for pesticide contamination. Thus, at least $470 million is invested by state and federal governmental organizations.

Although enormous amounts of government funds are being spent to reduce pesticide pollution, many costs of pesticides are not taken into account. Also, many serious environmental and social problems remain to be corrected by improved government policies.

4.13 Ethical and Moral Issues

Although pesticides provide about $40 billion per year in saved U.S. crops, the data of this analysis suggest that the environmental and social costs of pesticides to the nation total approximately $10 billion. From a strictly cost/benefit approach, it appears that pesticide use is beneficial. However, the nature of the environmental and public health costs of pesticides has other trade-offs involving environmental quality and public health.

One of these issues concerns the importance of public health vs. pest control. For example, assuming that pesticide-induced cancers number more than 10,000 cases per year and that pesticides return a net agricultural benefit of $32 billion per year, each case of cancer is “worth” $3.2 million in pest control. In other words, for every $3.2 million in pesticide benefits, one person falls victim to cancer. Social mechanisms and market economics provide these ratios, but they ignore basic ethics and values.

In addition, pesticide pollution of the global environment raises numerous other ethical questions. The environmental insult of pesticides has the potential to demonstrably disrupt entire ecosystems. All through history, humans have felt justified in removing forests, draining wetlands, and constructing highways and housing in various habitats. L. White (1967) has blamed the environmental crisis on religious teachings of mastery over nature. Whatever the origin, pesticides exemplify this attempt at mastery, and even a noneconomic analysis would question its justification. There is a clear need for a careful and comprehensive assessment of the environmental impacts of pesticides on agriculture and natural ecosystems.

In addition to the ethical status of ecological concerns are questions of economic distribution of costs. Although farmers spend about $10 billion per year for pesticides, little of the pollution costs that result are borne by them or the pesticide producing chemical companies. Rather, most of the costs are borne off-site by public illnesses and environmental destruction. Standards of social justice suggest that a more equitable allocation of responsibility is desirable.

These ethical issues do not have easy answers. Strong arguments can be made to support pesticide use based on social and economic benefits. However, evidence of these benefits should not cover up the public health and environmental problems. One goal should be to maximize the benefits while at the same time minimizing the health, environmental and social costs. A recent investigation pointed out that U.S. pesticide use could be reduced by one-half without any reduction in crop yields (Pimentel et al., 1993b). The judicious use of pesticides could reduce the environmental and social costs, while it benefits farmers economically in the short-term and supports sustainability of agriculture in the long-term.

Public concern over pesticide pollution confirms a national trend toward environmental values. Media emphasis on the issues and problems caused by pesticides has contributed to a heightened public awareness of ecological concerns. This awareness is encouraging research in sustainable agriculture and in nonchemical pest management.

Granted, substituting nonchemical pest controls in U.S. agriculture would be a major undertaking and would not be without its costs. The direct and indirect benefits and costs of implementation of a policy to reduce pesticide use should be researched in detail. Ideally, such a program should both enhance social equitability and promote public understanding of how to better protect public health and the environment, while abundant, safe food is supplied. Clearly, it is essential that the environmental and social costs and benefits of pesticide use be considered when future pest control programs are being considered and developed. Such costs and benefits should be given ethical and moral scrutiny before policies are implemented, so that sound, sustainable pest management practices are available to benefit farmers, society, and the environment.

4.14 Conclusion

An investment of about $10 billion in pesticide control each year saves approximately $40 billion in U.S. crops, based on direct costs and benefits. However, the indirect costs of pesticide use to the environment and public health need to be balanced against these benefits. Based on the available data, the environmental and public health costs of recommended pesticide use total more than $9 billion each year (Table 4.6). Users of pesticides pay directly only about $3 billion, which includes problems arising from pesticide resistance and destruction of natural enemies. Society eventually pays this $3 billion plus the remaining $9 billion in environmental and public health costs (13.6).

Table 4.6 Total estimated environmental and social costs from pesticide in the United States

Costs	Millions of $/year
Public health impacts	1, 140
Domestic animals deaths and contaminations	30
Loss of natural enemies	520
Cost of pesticide resistance	1, 500
Honeybee and pollination losses	334
Crop losses	1, 391
Fishery losses	100
Bird losses	2, 160
Groundwater contamination	2, 000
Government regulations to prevent damage	470
Total	9, 645

Our assessment of the environmental and health problems associated with pesticides was made more difficult by the complexity of the issues and the scarcity of data. For example, what is an acceptable monetary value for a human life lost or a cancer illness due to pesticides? Equally difficult is placing a monetary value on killed wild birds and other wildlife; on the dearth of invertebrates, or microbes lost; or on the price of contaminated food and groundwater.

In addition to the costs that cannot be accurately measured, there are many costs that were not included in the $12 billion figure. If the full environmental, public health and social costs could be measured as a whole, the total cost might be nearly double the $12 billion figure. Such a complete and long-term cost/benefit analysis of pesticide use would reduce the perceived profitability of pesticides.

The efforts of many scientists to devise ways to reduce pesticide use in crop production while still maintaining crop yields have helped but a great deal more needs to be done. Sweden, for example, has reduced pesticide use by 68% without reducing crop yields and/or the cosmetic standards (PCC, 2002). At the same time, public pesticide poisonings have been reduced 77%. It would be helpful, if the United States adopted a similar goal to that of Sweden. Unfortunately with some groups in the U.S., IPM is being used as a means of justifying pesticide use.

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