Indiana Journal of Global Legal Studies

Volume 9 | Issue 1 Article 4

Fall 2001

Overview of the Use of Genetically Modified Organisms and Pesticides in Agriculture`

David Pimentel
Cornell University

Overview of the Use of Genetically Modified Organisms and Pesticides in Agriculture

DAVID PIMENTEL*

INTRODUCTION

Sustainable agricultural development is critically needed because of rapid human population growth and the serious food shortages that exist in the world today.[1] The world population is projected to double from six billion to twelve billion in about fifty years, based on the current rate of growth.[2] Even if a policy of 2.1 children per couple were adopted tomorrow, instead of the current 2.9 children, the world population would continue to increase for approximately seventy years before stabilizing at nearly twelve billion.[3] The "population momentum," or current young age distribution, in most countries is responsible for the continued population growth, even assuming a change in the average to 2.1 children per couple. Clearly, nations with a median population age of only sixteen years will continue to grow for the full seventy years.[4]

Population growth creates a need for more food, water, shelter, and jobs. Signaling the seriousness of the human population explosion are the recent World Health Organization reports indicating that more than 800 million people are malnourished.[5] This is the largest number, in both absolute and relative terms, of malnourished people ever reported in history. Malnourishment is extremely serious because it increases susceptibility to other major diseases such as malaria, diarrhea, and AIDS.[6] Sick and diseased people find it difficult to work or even to

* Professor of Ecology and Agricultural Science, College of Agriculture and Life Sciences, Cornell University, Ithaca, NY 14853-0901. E-mail: dp18@cornell.edu.

1. *See* David Pimentel et al., *Will the Limits of the Earth's Resources Control Human Numbers?* (Feb. 25, 1999), http://dieoff.org/page174.pdf [hereinafter Pimentel et al., *Will the Limits of the Earth's Resources Control Human Populations?*]; David Pimentel & Maurizio Pimentel, *Feeding the World's Population*, 50 BIOSCIENCE 387, 387 (2000) [hereinafter Pimentel & Pimentel, *Feeding the World's Population*].

2. POPULATION REFERENCE BUREAU, 2000 WORLD POPULATION DATA SHEET 2 (2000).

3. *See* Pimentel et al., *Will the Limits of the Earth's Resources Control Human Populations?*, *supra* note 1, at 11.

4. POPULATION REFERENCE BUREAU, *supra* note 2, at 2.

5. WHO, *Nutrition*, http://www.who.int/nut/nutrition2.htm (last updated July 23, 2001).

6. *See* David Pimentel et al., *Ecology of Increasing Disease: Population Growth and Environmental Degradation*, 48 BIOSCIENCE 817, 817-26 (1998) [hereinafter Pimentel et al., *Ecology of Increasing Disease*]; Pimentel et al., *Will the Limits of the Earth's Resources Control Human Populations?*, *supra* note 1, at 10-11.

enjoy their daily lives. Per capita shortages of basic food resources are a primary cause of this malnutrition;[7] poverty and inadequate or unfair distribution of food supplies are contributing factors.[8] Cereals are the mainstay of human diets, comprising about eighty percent of the world food supply. Food availability per capita as measured by cereals has been declining since 1984.[9] Although cereal grain harvests per hectare have increased slightly since 1984, these harvests must be divided among more people, thereby decreasing the per capita availability.

Yet at a time when food production should be increasing dramatically to meet the needs of a rapidly expanding population, world cropland per capita declined twenty percent during the past decade.[10] Yearly, more than ten million hectares of cropland are degraded and lost due to wind and water erosion.[11] Erosion is intensifying worldwide, especially in developing countries where the rural poor remove crop residues for fuel and cooking, and where overgrazing is widespread.[12] Valued forests are being removed, and marginal lands are being cultivated out of necessity. Farmers require irrigation water in arid regions; however, in part because of salinization and waterlogging, irrigated cropland per capita has declined about five percent since 1978.[13] In some regions, farmers simply cannot afford to irrigate, so less available land is being utilized.

Thus, although no one knows exactly how large the human population will be fifty years from now, we do know that the more than six billion people already living on earth are stressing the earth's land, water, and biological resources, and are polluting the environment.[14] In addition, we know there are too many malnourished people. To improve the growing imbalance between human population numbers and available food supply, humans should actively conserve cropland, freshwater, energy, and biological resources. Populations in developed countries could contribute by reducing their high consumption of resources. And, importantly, the development of appropriate and safe biotechnologies using both genetically modified organisms (GMOs) and non-chemical pest control

---

7. *See* Pimentel & Pimentel, *Feeding the World's Population,* supra note 1, at 387.

8. *See* Pimentel et al., *Will the Limits of the Earth's Resources Control Human Populations?*, *supra* note 1, at 11.

9. *Id.* at 13.

10. *Id.* at 2-3, 14.

11. David Pimentel & Nadia Kounang, *Ecology of Soil Erosion in Ecosystems*, 1 ECOSYSTEMS 416,418(1998).

12. David Pimentel, *The Limitations of Biomass Energy*, *in* ENCYCLOPEDIA ON PHYSICAL SCIENCES & TECHNOLOGY (forthcoming 2001).

13. *See* SANDRA POSTEL, PILLAR OF SAND: CAN THE IRRIGATION MIRACLE LAST? 60 (1999).

14. *See* Pimentel et al., *Will the Limits of the Earth's Resources Control Human Populations?*, *supra* note 1, at 9-10.

technologies holds the promise of improving food production.[15] Sustainable agricultural development requires humans to be brave enough to limit their numbers, or nature will impose its own limits.

This paper provides an overview of the use of GMOs and pesticides. Part I examines the following aspects of GMOs: benefits, disease resistance in crops, insect resistance in crops, and herbicide resistance in crops. Part II then discusses the following aspects of pesticide use in agriculture: crop losses to pests and the benefits of pesticides, the amount of pesticides reaching target pests, the effects of pesticide use on public health, and environmental impacts of pesticides.

I. GMOs

A. Benefits

Since the 1980s, many crops have been genetically modified to create benefits such as resistance to insects, pathogens (including viruses), and herbicides. In addition, many crops have been genetically modified for improved features such as slower spoilage, improved nutrition, high protein, seedless fruit, and sweetness. Up to thirty-four new genetically engineered crops have been approved to enter the market.[16]

Since 1986, more than 2,000 field trials have led to the release of transgenic plants around the world.[17] In 1999, forty million hectares[18] of engineered crops

15. *See* Maurizio G. Paoletti & David Pimentel, *Environmental Risks of Pesticides Versus Genetic Engineering for Agricultural Pest Control*, 12 J. AGRIC. & ENVTL. ETHICS 279, 279 (2000) [hereinafter Paoletti & Pimentel, *Environmental Risks*]; David S. Pimentel & Peter H. Raven, *Bt Corn Pollen Impacts on Nontarget Lepidoptera: Assessment of Effects in Nature*, 97 PROCS. NATL. ACAD. SCI. U.S. AM. 8198, 8198-99 (2000), *available at* http://www.biotech-info.net/Bt_impacts_nontarget.html.

16. R. L. Fuchs et al., *Safety Evaluation of Genetically Engineered Plants and Plant Products: Insect-Resistant Cotton, in* BIOTECHNOLOGY & SAFETY ASSESSMENT 199, 200 (John A. Thomas & Laurie A. Myers eds., 1993); *see also* R.B. Head, Nat'l Cotton Council of Am., *Cotton Insect Losses*, 2 PROC. BELTWIDE COTTON PRODUCTION RES. CONF. 655 (1991), *available at* http://www.cotton.org/beltwide/proceedings.cfm.

17. Paoletti & Pimentel, *Environmental Risks*, *supra* note 15, at 285; *see also* Clive James & Anatole F. Krattiger, *The ISAAA Biosafety Initiative: Institutional Capacity Building through Technology Transfer, in* BIOSAFETY FOR SUSTAINABLE AGRICULTURE: SHARING BIOTECHNOLOGY REGULATORY EXPERIENCES OF THE WESTERN HEMISPHERE 225 (Anatole F. Krattinger & Arno Rosemarin eds., 1994).

18. CLIVE JAMES, INT'L SERV. FOR THE ACQUISITION OF AGRI-BIOTECH APPLICATIONS [ISAAA], BRIEF NO. 17, GLOBAL REVIEW OF COMMERCIALIZED TRANSGENIC CROPS: 1999 (2000), http://www.isaaa.org/publications/briefs/Brief_17.htm [hereinafter JAMES, Brief No. 17]. In 1998, only 27.8 million hectares of engineered crops were planted. *See* CLIVE JAMES, ISAAA, BRIEF NO. 8, GLOBAL REVIEW OF COMMERCIALIZED TRANSGENIC CROPS: 1998 (1998), http://www.isaaa.org/publications/briefs/Brief_8.htm

were planted in countries including the United States, Argentina, Canada, and Australia. The United States alone contains seventy-two percent of modified cropland planted.[19] Globally, sixty-nine percent of this area has been planted with herbicide tolerant crops, ten percent with insect resistant crops, and twenty-one percent with insect and herbicide resistant crops. Five crops—soybeans, corn, cotton, canola, and potatoes—cover the largest acreage of engineered crops.[20]

B. Disease Resistance in Crops

Seventy-five percent to 100 percent of all crops have some degree of plant pathogen resistance bred into the crop. Most of this resistance was added by farmer selection and/or by plant breeder selection; little of the resistance has been added by the use of GMOs.[21] Because of this natural resistance that has been bred into the crops, twelve percent of the pesticides used in U.S. agriculture are fungicides.[22] Of course, the use of GMO technology to increase disease resistance in crops has the potential further to reduce fungicide use in agriculture.

There are potential risks to the large-scale cultivation of plants expressing viral and bacterial genes in crops. The most significant risk is the potential for gene transfer of disease resistance from cultivated crops to weed relatives.[23] For example, it has been postulated that a virus-resistant squash could transfer its newly acquired virus-resistance genes to wild squash, which is native to the southern United States. If the virus-resistance genes spread, newly disease-resistant weed squash could become a hardier, more abundant weed.[24] Moreover, because squash originates in the United States, changes in the genetic make-up of wild squash could conceivably lessen its value to squash breeders.

[hereinafter JAMES, Brief No. 8]; Anne Simon Moffat, *Toting up the Early Harvest of Transgenic Plants*, 282 SCIENCE 2176, 2178 (1998).

19. JAMES, Brief No. 17, *supra* note 18. In 1998, the U.S. contained 74%. JAMES, Brief No. 8, *supra* note 18.

20. JAMES, Brief No. 17, *supra* note 18.

21. *See* Maurizio G. Paoletti & David Pimentel, *Genetic Engineering in Agriculture and the Environment: Assessing Risks and Benefits*, 46 BIOSCIENCE 665, 667 (1996) [hereinafter Paoletti & Pimentel, *Genetic Engineering*].

22. David Pimentel et al., *Environmental and Economic Effects of Reducing Pesticide Use in Agriculture* 46 AGRIC., ECOSYSTEMS & ENV'T 273, 274 (1993) [hereinafter Pimentel et al., *Environmental and Economic Effects of Reducing Pesticide Use in Agriculture*].

23. *See* Paoletti & Pimentel, *Genetic Engineering*, *supra* note 21, at 668.

24. The U.S. Department of Agriculture argues that viruses do not appear to infect wild squash. This argument is questionable, however, because the Department based its conclusion largely on a survey of only 14 wild squash plants in which no viral infection was detected. Rebecca Goldburg, *Pause at the Amber Light*, 27 CERES 21, 23 (1995).

An assessment of potential socioeconomic implications related to the introduction of some genetically modified varieties of virus-resistant potatoes in Mexico underscores the important implications of this technology. The mycoplasma and virus diseases in Mexico are not currently controlled with pesticides, and rank second in economic damages based on crop losses due to plant pathogens. The major pest of the potato, the fungus *Phytophthora infestans*, ranks first in economic damages and requires, in some cases, up to thirty fungicide applications. While the genetic modification of potatoes could prove especially beneficial to large-scale farmers; however, it would be only marginally beneficial to small-scale farmers, because most small farmers use red potato varieties that are not considered suitable for GMO transformation. In addition, seventy-seven percent of the seeds that small farmers use come from informal sources, not from the commercial seed providers that could sell the new resistant varieties.[25]

C. *Insect Resistant Crops*

Although insect resistant crops have not been employed as widely as disease resistant crops, notable examples of insect resistant crops include Hessian fly resistance in wheat and European corn-borer resistance in corn.[26] The use of *Bacillus thuringiensis* (Bt) toxin genes in corn to control the European corn-borer has had both benefits and problems. The most serious problem occurred with Starlink corn. This variety of corn with Bt toxin was approved for use only as animal feed, and could not be fed to humans.[27] Unfortunately, those who sold the Starlink commercial seed did not emphasize this restriction, and, as a result, some of the corn found its way into the food processing industry. Many millions of dollars of processed food had to be disposed of because of the Bt toxin restriction.

The effects of Bt corn-pollen on non-target Lepidoptera have raised serious questions about this technology. Demonstrations that milkweed leaves dusted with Bt pollen are toxic to Monarch butterfly larvae feeding on them are

---

25. MATIN QAIM, ISAAA, BRIEF NO. 7, TRANSGENIC VIRUS RESISTANT POTATOES IN MEXICO: POTENTIAL SOCIOECONOMIC IMPLICATIONS OF NORTH-SOUTH BIOTECHNOLOGY TRANSFER 11 (1998), http://www.isaaa.org/publications/briefs/Brief_7.htm.

26. *See* Pimentel et al., *Environmental and Economic Effects of Reducing Pesticide Use in Agriculture*, *supra* note 22, at 279-80.

27. Marc Kaufman, *Biotech Critics Find Banned Corn in Food*, DENVER POST, Sept. 18, 2000, at A1.

consistent with the known toxicity of Bt endotoxin to Lepidoptera in general.[28] Much speculation and some investigations followed these studies concerning the extent to which the poisoning of Monarch butterflies and other non-target Lepidoptera might be significant contributors to the mortality of these insects in nature.[29]

Recently, Wraight reported that experiments with populations of black swallowtail butterfly under field conditions resulted in no mortality from BT corn planted adjacent to food plants of this butterfly.[30] It has not been demonstrated, however, that Monarch butterflies and black swallowtail butterflies are equally susceptible to Bt endotoxins. Further, the Wraight study demonstrated that the pollen of the corn strain 176 used in earlier experiments with the Monarch butterfly was lethal to black swallowtail larvae.[31] However, the pollen of the strain that was used in their experiments had 1/40th of the BT endotoxin level that strain 176 had and was not toxic to caterpillars.[32] In any event, the level of Bt endotoxin in the pollen of this particular corn strain, as expected, is highly toxic to Monarch butterfly larvae.

Another recent study concluded that the impacts of Bt corn on Monarch butterflies is probably less than the impact from other factors, such as human population growth, the loss of habitat for Monarch butterflies, and the toxicity of applied pesticides.[33] Supporting this conclusion is the fact that the Monarch butterfly was in trouble long before the Bt corn was planted extensively. From 1996 and 1997 to 1998 and 1999, for example, the overwintering Monarch butterfly populations in Mexico declined from 170 to 204 million to only fifty-six to sixty-seven million.[34]

28. John E. Losey et al., *Transgenic Pollen Harms Monarch Larvae*, 399 NATURE 214, 214 (1999); Laura C. Hansen Jesse & John J. Obrycki, *Field Deposition of Bt Transgenic Corn Pollen: Lethal Effects on the Monarch Butterfly*, 125 OECOLOGIA 241, 247 (2000).

29. For example, Shelton and Roush were critical of the two earlier findings, but did not provide any data from nature. Anthony M. Shelton & Richard T. Roush, *False Reports and the Ears of Men*, 17 NATURE BIOTECH. 832, 832 (1999).

30. C. L. Wraight et al., *Absence of Toxicity of Bacillus Thuringiensis Pollen to Black Swallowtails Under Field Conditions*, 97 PROC. NAT'L ACAD. SCI. U.S. AM. 7700, 7702-03 (2000).

31. *Id.*

32. For their study, Losey et al. used still a different strain, N4640. Losey et al., *supra* note 28, at 214.

33. *See* Pimentel & Raven, *supra* note 15, at 8199.

34. *Butterflies & Bt Corn Pollen: Lab Research & Field Realities*, http://www.biotechknowledge.monsanto.com (Feb. 15, 2000).

D. Herbicide Resistant Crops (HRCs)

Several engineered crops that feature herbicide resistance are commercially available, and thirteen other key crops in the world may be available soon. In addition, some crops, including corn, are being engineered to contain both herbicide (glyphosate) and biotic insecticide resistance (BT d-endotoxin).[35] Some specialists suggest that herbicides adopted for herbicide-resistant crops employ lower doses when compared with atrazine, 2, 4-D, and andalachlor. The resistance of the crop to the target herbicide, however, would in practice lead the farmer to apply dosages higher than recommended.[36] In addition, the cost of this new herbicide resistance technology is about two times higher in corn than the cost of the recommended herbicide use and soil cultivation for weed control.[37]

Integrated pest management could benefit from some HRCs, if alternative non-chemical methods were applied first, to control weeds and the target herbicide were then used only when and where the economic threshold of weeds was surpassed.[38] Generally, however, the use of herbicide resistant crops will lead to increased herbicide use and environmental and economic problems.[39]

II. PESTICIDES

A. Crop Losses

Despite the agricultural application of nearly three billion kilograms of pesticides each year, pests destroy more than forty percent of all potential crop production worldwide.[40] Insects are believed to be responsible for fifteen percent of the losses, plant pathogens for thirteen percent, and weeds for an additional twelve percent of the losses. In addition to the pre-harvest loss of more than forty percent, the post-harvest loss caused by pests is estimated to be about

35. Union of Concerned Scientists, *What's Coming to Market?: An Update on US Commercialization*, GENE EXCHANGE, Fall 1997, at 6, 6-8.

36. *See* Paoletti & Pimentel, *Genetic Engineering*, *supra* note 21, at 667.

37. *See* David Pimentel & Madinah S. Ali, *An Economic and Environmental Assessment of Herbicide-Resistant and Insect/Pest Resistant* Crops, 7 INDIAN J. APPLIED ECON. 241, 247 (1998).

38. SHELDON KRIMSKY & ROGER P. WRUBEL, AGRICULTURAL BIOTECHNOLOGY AND THE ENVIRONMENT: SCIENCE, POLICY, AND SOCIAL ISSUES 42 (1996).

39. *See* Paoletti & Pimentel, *Genetic Engineering*, *supra* note 21, at 667-68; *see also* Pimentel & Ali, *supra* note 37; Miguel A. Altieri, *The Environmental Risks of Transgenic Crops: An Agroecological Assessment*, *at* http://www.bdt.org.br/binas/Library/cabi/altieri.html (last visited Nov. 12, 2001).

40. DAVID PIMENTEL, TECHNIQUES FOR REDUCING PESTICIDE USE: ECONOMIC AND ENVIRONMENTAL BENEFITS 2 (1997).

twenty percent in developing countries.[41] Adding the post-harvest losses to the harvest loss of forty percent, the total loss of all food to pests is therefore nearly fifty-two percent. I would then add at least a two percent pre-harvest loss from rats and other rodents. The estimated loss of fifty-four percent of potential food is a terrible loss when the world needs all the food that it can supply.

B. Pesticides Reaching Target Pests

Few appreciate the fact that less than 0.1 percent of the pesticide applied actually reaches the target pests, which means that more than 99.9 percent contaminates the environment.[42] In many cases, the leaf surface areas of the crop plant have to be covered with fine pesticide particles to protect the plant from microbes and small insect pests. Aerial application of pesticides is one of the most ineffective means of applying pesticides to the target crop. For instance, using ultra-low-volume spray equipment only gets about twenty-five percent of the pesticide into the target area.[43] This means that seventy-five percent drifts into the non-target environment. It is worth emphasizing that twenty-five percent of the pesticide reaches the target area only when the application is made under ideal conditions—that is, with little or no wind.

In the United States, approximately thirty-five percent of all foods in supermarkets have detectable pesticide residues, and at least one to three percent of all foods have residues above the Food and Drug Administration's acceptable tolerance level.[44] In contrast, in India, 97.5 percent of the foods sold in markets have detectable pesticide residues, and twenty-five percent of the foods have residues above the acceptable tolerance level.[45]

41. D. Cao et al., *Postharvest Food Losses (Vertebrates), in* ENCYCLOPEDIA OF PEST MANAGEMENT (David Pimentel ed., forthcoming 2002).

42. David Pimentel & Lois Levitan, *Pesticides: Amounts Applied and Amounts Reaching Pests*, 36 BIOSCIENCE 86, 90 (1986).

43. David Pimentel et al., *Environmental and Economic Impacts of Reducing U.S. Agricultural Pesticide Use, in* 1 CRC HANDBOOK OF PEST MANAGEMENT IN AGRICULTURE 679 (David Pimentel et al. eds., 2d ed. 1991) [hereinafter Pimentel et al., *Environmental and Economic Impacts of Reducing U.S. Agricultural Pesticide Use*].

44. David Pimentel & Kelsey Hart, *Pesticide Use: Ethical, Environmental, and Public Health Implications, in* NEW DIMENSIONS IN BIOETHICS: SCIENCE, ETHICS AND THE FORMULATION OF PUBLIC POLICY 79, 89-90 (Arthur W. Galstan & Emily G. Schurr eds., 2001); David Pimentel et al., *Ecology of Increasing Disease*, *supra* note 6.

45. U. K. SRIVASTAVA & N. T. PATEL, PESTICIDES INDUSTRY IN INDIA: ISSUES AND CONSTRAINTS IN ITS GROWTH 89-91 (1990).

C. Pesticides and Public Health

Since the advent of DDT use for crop protection in 1945, the global growth of agricultural pesticide use has been phenomenal. In 1945, about fifty million kilograms of pesticides were applied worldwide. Exhibiting an approximate sixty-fold increase, global usage is currently at about three billion kilograms per year.[46] In the United States, the annual use of synthetic pesticides have grown thirty-three-fold to about 0.5 billion kilograms since 1945.[47] Unfortunately, the increase in hazards is even greater than it might appear, as the toxicity of modern pesticides has increased more than ten-fold as compared to those used in the early 1950s.[48] In 1945, when synthetic pesticides were first used, there were few pesticide poisonings. Globally, pesticide use increased to a high of 1.3 billion kilograms per year by 1973. At that time, the number of human pesticide poisonings reached an estimated 500,000 (with about 6,000 deaths annually).[49] Two decades later, the World Health Organization reports approximately three million human pesticide poisonings each year worldwide.[50] Approximately 220,000 cases each year result in death, and an estimated 735,000 result in chronic illnesse.[51] Several pesticides, especially the organophosphate and carbamate classes, affect the nervous system by inhibiting cholinesterase.[52] This is particularly critical in children, since a child's brain is more than five times larger in proportion to its body weight than an adult's.[53] In California, forty percent of the children working in agricultural fields have blood cholinesterase levels below normal, indicating organophosphate and carbamate pesticide poisoning.[54]

---

46. *See* Pimentel et al., *Environmental and Economic Impacts of Reducing U.S. Agricultural Pesticide Use*, *supra* note 43.

47. Pimentel et al., *Ecology of Increasing Disease*, *supra* note 6.

48. David Pimentel, *Pesticides: Energy Use in Chemical Agriculture*, Accademia Nazionale Delle Scienze, MEMORIE DI SCIENZE FISICHE E NATURALI (1987) (presented at *Towards a Second Green Revolution: From Chemical to New Biological Technologies in Agriculture in the Tropics* (Sept. 8-10, 1986)).

49. Ronald N. Labonte, M.A., *Pesticides and Healthy Public Policy*, 80 CAN. J. PUB. HEALTH 238, 238 (1989).

50. WHO, OUR PLANET, OUR HEALTH: REPORT OF THE WHO COMMISSION ON HEALTH & ENVIRONMENT 79-81 (1992).

51. *Id.*

52. D.J. Ecobichon et al., *Neurotoxic Effects of Pesticides*, *in* THE EFFECT OF PESTICIDES ON HUMAN HEALTH 131, 145 (Scott R. Baker & Chris F. Wilkinson eds., 1988).

53. *See* JOHN WARGO, OUR CHILDREN'S TOXIC LEGACY: HOW SCIENCE AND LAW FAIL TO PROTECT US FROM PESTICIDES 173 (1996).

54. *See* ROBERT REPETTO & SANJAY S. BALIGA, WORLD RESOURCES INSTITUTE, PESTICIDES AND THE IMMUNE SYSTEM: THE PUBLIC HEALTH RISKS 13 (1996).

Occupational exposure to pesticides and other toxic chemicals has been the best source of information about chemical diseases. Data on the effects of pesticides in the general population, however, are less reliable because of complicating factors including low concentrations, synergistic effects of multiple contaminants, and low-level chronic exposures. This complexity makes it extremely difficult to identify the causative chemicals. This difficulty is illustrated in India. A medical doctor in the Kerala village in India observed relatively high rates of disorders in the central nervous system of children, including cerebral palsy, congenital anomalies, and mental retardation.[55] Finally, the doctor discovered alarmingly high rates of the insecticide endosulfan in the population. One woman's blood was found to have an endosulfan level 900 times greater than the acceptable level for drinking water![56]

D. Environmental Impacts of Pesticides

The environmental effects of pesticides are extremely complex: one must account for about ten million non-target organisms, water and soil contamination, air pollution, and the use of more than 700 pesticide chemicals. Because of the complexity of the agricultural and natural ecosystems, therefore, little is known about the environmental impacts of pesticides. However, sufficient information is available to cause concern. A brief discussion of the range of pesticide effects follows, using data primarily from the United States.

In addition to affecting humans, pesticides poison thousands of domestic animals each year in the United States and throughout the world. Dogs and cats represent the largest number of domestic animals poisoned, because they usually wander freely about the home and farm, and therefore have greater opportunity to come into contact with pesticides than other domestic animals.[57]

Pesticides also affect the population of natural enemies. In both natural and agro-ecosystems, many species, especially predators and parasites, control or help to control pest populations. Indeed, these naturally beneficial species make it possible for natural and agro-ecosystems to remain "green."[58] Without natural

---

55. *See* Centre for Sci. & Env't, *How Do We Break This Conspiracy of Silence*, http://www.cseindia.org/html/extra/invikerala.htm (last visited Oct. 5, 2001).

56. *Id.*

57. *See* Pimentel & Hart, *supra* note 44, at 83-84.

58. David Pimentel et al., *Assessment of Environmental and Economic Costs of Pesticide Use*, *in* THE PESTICIDE QUESTION: ENVIRONMENT, ECONOMICS, AND ETHICS 47, 55 (David Pimentel & Hugh Lehman eds., 1993) [hereinafter Pimentel et al., *Assessment of Environmental and Economic Costs of Pesticide Use*].

enemies and biological control in agriculture, losses of food to pests would increase as much as fifty-eight percent.[59] This has been confirmed in U.S. agriculture when pesticides have been found to reduce or totally destroy natural enemy populations. Such destruction resulted in an explosion of pest insect populations. In the United States, experts estimate that the destruction of natural enemies in agro-ecosystems cost the nation more than $500 million each year.[60]

In addition to destroying natural enemy populations, the extensive use of pesticides has resulted in the development of pesticide resistance in many insect pests, plant pathogens, weeds, and rats.[61] The United Nations Programme reported a few years ago that pesticide resistance was one of the four most serious environmental problems.[62] Worldwide, more than 500 insect and mite species, more than 150 plant pathogen species, and more than 275 species of weeds have become resistant to herbicides. The estimated cost of pesticide resistance in pests in the United States is at least $1.4 billion annually.[63]

Pesticide use also has an adverse effect on the pollination process. Honey and wild bees are vital for pollination of about one-third of fruits, vegetables, and other crops worldwide.[64] Bee pollination in the United States has estimated benefits worth approximately $40 billion per year.[65] Pesticide-related damage to honey and wild bee populations in the United States alone is estimated to cost approximately $320 million per year.[66]

While pesticides are applied to protect crops from pests in order to increase yields, they sometimes damage the crops they are designed to protect. 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 in rotation

59. *Id.*

60. *Id.* at 55; *see* David Pimentel & Anthony Greiner, *Environmental and Socio-Economic Costs of Pesticide Use, in* TECHNIQUES FOR REDUCING PESTICIDE USE: ECONOMIC AND ENVIRONMENTAL BENEFITS 51, 58 (David Pimentel ed., 1997).

61. Pimentel et al., *Assessment of Environmental and Economic Costs of Pesticide Use, supra* note 58, at 55.

62. Pimentel et al., *Ecology of Increasing Disease, supra* note 6.

63. *See* Pimentel & Greiner, *supra* note 60, at 60.

64. *See* David Pimentel et al., *Economic and Environmental Benefits of Biodiversity*, 47 BIOSCIENCE 747, 753 (1997).

65. *Id.* at 758.

66. *See* Pimentel & Greiner, *supra* note 60, at 62.

> or inhibit the growth of crops that are planted; and/or (4) excessive pesticide residues accumulate on crops, necessitating the destruction of the harvest.[67]

Estimated crop and tree losses in the United States that are attributable to recommended pesticide use is nearly $1 billion per year.[68]

Ground and surface water contamination from pesticides is also a serious problem worldwide. In the United States alone, an adequate test of water resources for pesticide residues would cost the nation about $1.3 billion annually.[69] In addition, there are serious fish kills and losses due to fish contamination. One estimate of fish losses is well over $10 million per year.[70]

In the United States, about three kilograms of pesticides are applied per hectare per year.[71] Wild birds and mammals are damaged by these pesticide applications. It is estimated that nearly seventy million birds are killed each year from pesticide applications.[72] The economic value of these birds is approximately $2 billion each year.

Accounting for all of these effects, a conservative estimate of the total damage to the environment and public health caused by pesticides is about $9 billion each year.

CONCLUSION

Both pesticides and biotechnology have definite advantages in reducing pest-related crop losses, and in helping to feed the more than 800 million people who are malnourished in the world, as well as the other five billion.[73] At present, pesticides are used more widely than biotechnology, and thus are playing a greater role in protecting world food supplies. Relatedly, because of this more widespread use, pesticides currently have a greater negative impact than biotechnology or GMOs in terms of environmental and public health effects.

---

67. *See* Pimentel & Hart, *supra* note 44, at 88.
68. Pimentel & Greiner, *supra* note 60, at 65.
69. *Id.* at 66.
70. *See* Pimentel & Hart, *supra* note 44, at 92.
71. *See* Pimentel & Greiner, *supra* note 60, at 67.
72. *See* Pimentel et al., *Assessment of Environmental and Economic Costs of Pesticide Use*, *supra* note 58, at 68.
73. WHO, Nutrition, http://www.who.int/nut/nutrition2.htm (last modified July 23, 2001).

Genetically engineering crops for resistance to insect pests and plant pathogens could in most cases be environmentally beneficial, because these resistant crops could help to reduce the use of hazardous insecticides and fungicides in crop production. In time, there may also be economic benefits for farmers who use genetically engineered crops; this will depend, though, on the prices charged by the biotechnology firms for the transgenic crops.

There are, however, some environmental problems associated with the use of genetically engineered crops in agriculture. For example, adding Bt to crops like corn for insect control can result in many of the following negative environmental consequences: (1) development of resistance to BT by pest species in corn and other crops; (2) potential health risks from human exposure to the Bt toxin in their food and to livestock in feed; and (3) the toxicity of the pollen from the Bt-treated corn to Monarch butterflies, bees, beneficial natural enemies, and endangered species of insects that feed on the modified corn plants or come into contact with the drifting pollen.[74]

A major environmental and economic concern associated with genetically engineered crops is the development of herbicide-resistant crops. Although in a few instances HRCs may result in a reduction of toxic herbicide use, it is more likely that the use of herbicide-resistant crops will increase herbicide use and environmental pollution. In addition, farmers will suffer because of the high costs of employing herbicide-resistant crops: in some instances, weed control with HRCs may increase weed control costs two-fold.[75]

More than forty percent of the research conducted by biotechnology firms focuses on the development of herbicide resistant crops. This is not surprising, however, because most of the biotechnology firms are also chemical companies that stand to profit if herbicide use in crops increases sales.[76] Theoretically, the acceptance and use of engineered plants in sustainable and integrated agriculture should consistently reduce pesticide use, but this is not the current trend. In addition, most products and new technologies are designed for western agriculture systems, not for developing countries.[77] For example, if terminator genes enter the seed market, it will not be possible for traditional or small farmers

74. Paoletti & Pimentel, *Environmental Risks*, *supra* note 15, at 293-94.
75. *See* Pimentel & Ali, *supra* note 37, at 247.
76. *See* Paoletti & Pimentel, *Genetic Engineering*, *supra* note 21, at 667.
77. *See* Altieri, *supra* note 39; *see also* Moffat, *supra* note 18, at 2176.

to use their plants to produce seeds.[78] Thus, genetic engineering could promote improvements for the environment; however, the current products—especially herbicide-resistant crops and Bt-resistant crops—have serious environmental impacts.

78. *See* Jean-Pierre Berlan & Richard C. Lewontin, *La Menace du Complexe Génético-industriel*, LE MONDE DIPLOMATIQUE, Dec. 22, 1998, at 1.