PART **I**

OVERVIEW: NAMES AND CHARACTERISTICS OF PESTICIDES

chlorpyrifos permethrin oxamyl aldicarb limonene
bifenthrin flucythrinate thiodicarb cryolite metolachlor
acifluorfen oxyfluorfen fenoxaprop-ethyl chlorsulfuron
oxadiazon cinmethylin glyphosate sethoxydim
metalaxyl ethirimol bupirimate imazalil furalaxyl
triadimefon iprodione vinclozolin fenarimol triforine
brodifacoum bromadiolone diphacinone mecarbam
bensulide thiabendazole phoxim cyanazine paraquat
dazomet butazon carbaryl nicotine biphenyl
fospirate ioxynil ethazol malathion antu dimetilan
acrolein terbacil ziram propazine disulfoton
rotenone fonofos sulfur molinate sulfoxide
chlorazine captan warfarin trifluralin dicumarol
cycloheximide naptalam barban monuron fenac

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OVERVIEW: NAMES AND CHARACTERISTICS OF PESTICIDES

CHAPTER 1

Pesticides: Chemical and Biological Tools

Let's get our priorities in perspective…. We must feed ourselves and protect ourselves against the health hazards of the world. To do that, we must have agricultural chemicals. Without them, the world population will starve.

Norman E. Borlaug,
1970 Nobel Peace Prize

With our feet planted firmly in the 21st Century, humans can easily forget the long association between mankind and pests. Insects and other pests have been boon and bane to mankind. Man avoided biting arthropods and other harassing pests if possible, treated their effects if he could not, but adapted and learned to sustain himself against their onslaughts although at heavy cost to health and comfort. The passing centuries have not removed the threat of insects and other pests, but the techniques to mitigate their effects certainly have. The purpose of this new edition of *The Pesticide Book* is to update the review of a mainstay in the fight against pests, namely, *pesticides*.

Origin of pesticides—

In prehistory, as today, mankind acted to avoid ravages by pests. They hugged smoky fires or caked mud on themselves to avoid biting flies, made containers for food supplies they wished not to share with pests and generally used common sense and available tools to protect themselves.

Documentation attests to ancient pesticide use. More than 1000 years BC the Greek Poet, Homer, cited the anti-pest utility of sulfur. The Romans are known to have used salt to destroy the crops of their enemies and Democritus, the Greek Philosopher, drew attention to curative effects on blight afforded by applying olive oil processing residue to plants with certain diseases.

Pliny the Elder's *Natural History*, written in AD 70, includes a summary of pest control practices extracted from the Greek literature of the preceding 200-300 years. Most of the materials employed were useless, based on superstition and folklore.

Although the Chinese were using arsenic as an insecticide by AD 900 it was not until the mid-nineteenth century that pests were controlled with chemicals to any degree of success. Pyrethrum, lime and sulfur combination, arsenic, sulfur and soaps were the materials found to be effective between 1800 and 1825. Between 1825 and 1850 quassia, phosphorous paste and rotenone were employed. Mercurous chloride was used as a seed treatment during this period. The use of Bordeaux mixture (copper sulfate, lime and water) was started in France in 1865 to control downy mildew on grape vines; this mixture is still used today. With the use of Bordeaux mixture, the arsenical Paris green and kerosene emulsions as dormant sprays for deciduous fruit trees (1867-1868), the scientific use of pesticides had begun.

Advances in understanding the biology of pests undoubtedly enhanced the utility of pesticides beginning in the 19th Century. Application of pesticides at the specific time when the pests to be controlled are most vulnerable is the most precise use of a pesticide and is a subject continuously being reexamined by researchers.

Synthetic organic chemicals made their debut in the 1930's; 2-methyl-4,6-dinitrophenol (DNOC) was used in weed control and the first patent was issued for a dithiocarbamate fungicide (Zimdahl, 1978). The genesis of the modern era for pesticide use, however, began with the creation in 1939 and first use of the insecticide DDT during World War II.

The reader should examine Appendix A which provides a chronology of the important events in the development and use of pesticides covering the period 1200 BC through 2003. Such events include changes of company names, major industry mergers or acquisitions, the introduction of major new products or technologies, advances in formulation technology and also the demise of certain pesticides brought on by changing standards. In the past two decades or so, particularly following the creation of the US Environmental Protection Agency (EPA) in 1970, data requirements for registering and reregistering pesticides have become more demanding in both scope and depth. The process is a revolving one in which increasingly pesticide chemicals or their uses are being restricted or lost as a result of finding previously unknown subtle and potential long-range effects on the environment or nontarget organisms.

Definitions—

Pesticides— In simplest terms *pesticides* are agents employed by humans to destroy or control pests. The term "pesticide" is inclusive in that it applies to insecticides, herbicides, fungicides and other types of pest - controlling materials. The EPA as the primary regulator of pesticide use in the U.S. defines a pesticide more elaborately and legalistically: *A pesticide is any substance or mixture of substances intended for preventing, destroying, repelling or mitigating any pest.*

Pests are organisms that are competitive to mankind or his interests in some manner. Pests are defined by mankind and his life-style and preferences rather than by nature. To a farmer, pests may include a variety of species that compete with or damage his crops (insects, mites, weeds, nematodes, fungi, bacteria, viruses, snails, slugs, rodents, birds, etc.). To an urban or suburban-dweller pests may include annoying, disease-carrying flies, mosquitoes and cockroaches; moths that eat woolens; beetles that feed on leather goods or infest packaged foods; various insects and relatives that infest pets; slugs , snails, aphids, mites, beetles, caterpillars and bugs feeding on lawns, gardens and ornamentals; termites that nibble away wooden dwellings; diseases that mar and destroy plants;

algae growing on walls or clouding the water of swimming pools; slimes and mildews that grow on shower curtains and stalls and under the rims of sinks; rodents that steal food and leave behind their fecal pellets, dogs that urinate on shrubs and favorite flowers; alley cat yowls that interrupt sleep; and birds or bats that live in chimneys or defecate on window ledges, sidewalks and the statues of history's heroes. Every person, whether home bound, gardener or outdoor adventurer has encountered pests or their consequences and thereby intuitively have an appreciation for the term.

The role for pesticides—

Why are pesticides needed? Plants survive because of the sun and animals owe their survival to plants. Plants on which humans and other animals depend for life are susceptible to some 100,000 diseases caused by viruses, microorganisms or other plants. Crops grown to sustain humanity face competition from 30,000 weed species the world over, of which approximately 1800 species cause serious economic losses. More than 1000 of 3000 nematode species also cause severe economic loss to crops. Among the more than one million species of known insects, about 10,000 contribute to the devastating loss of crops worldwide. It is not only economic losses, however, that engender a need for effective pest control.

Worldwide, millions of humans are killed or disabled annually from insect-borne diseases and world losses from insects, diseases, weeds and rats are estimated at more than $100 billion annually. It is therefore obvious that control of various harmful organisms is vital for the future of agriculture, industry and human health. Pesticides thus become indispensable in feeding, clothing and protecting the world's population, which reached 6.0 billion on October 12th 1999, the "Day of Six Billions". The world's population is estimated to reach 8.04 billion by the year 2025 — an increase of 25% in only 25 years, the fastest rate of population growth in all history, (United Nations Population Reference Bureau 1999). In addition to this geometric increase in the numbers of humans, two other trends that have favored the use of pesticides have been the rapid advancement of sciences underlying pesticide technology and the consistent search in a free-market economy for faster, better, more economic and less labor intensive solutions.

Moreover, the deployment of pesticides in the 20th Century was one component of a new system. U.S. agriculture was transformed in the past century by the industrial revolution of the 19th Century. The adoption of steam and later, combustion engines, the advancements made in mechanization, the rise of refined petroleum products and new crop cultivars established a hunger in the U.S. for technology which has gone unabated. Increasing population brought new demands for more and better food and other agricultural products. Increased production, new land under tillage and more monoculture, brought more and more tenacious pest problems. Hence, when science offered new labor saving devices to public health and to agriculture (e.g. typhus control with DDT during WWII and caterpillar control on field crops), a new industry was borne.

How are pesticides used? A review of the contents of this book provides an overview of how pesticides are used. Table 1-1 comprises the list of common kinds of pesticides regulated by EPA. EPA excludes from their definition of "pesticide" certain classes or materials: drugs, fertilizers, nutrients, biological control agents and certain other low risk natural materials (cedar chips, garlic, Rosemary).

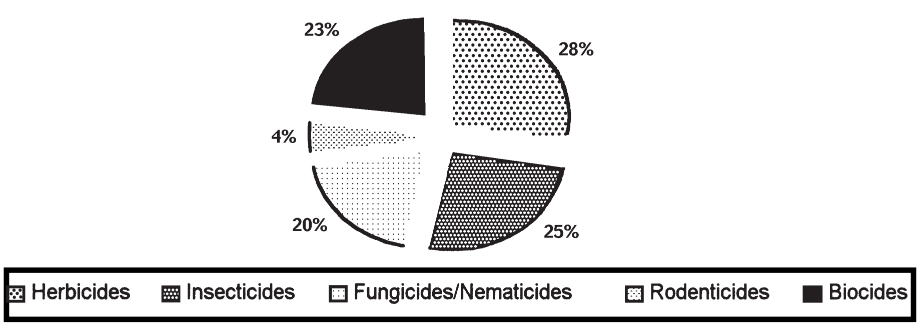
TABLE 1-1. Common Kinds of Pesticides
(http://www.epa.gov/pesticides/whatis.htm)

Algaecides	Fungicides	Pheromones
Antifouling agents	Herbicides	Plant Growth Regulators
Antimicrobials	Insect Growth Regulators	Repellents
Attractants	Insecticides	Rodenticides
Biocides	Miticides (acaricides)	
Defoliants	Microbial pesticides	
Desiccants	Molluscicides	
Disinfectants & sanitizers	Nematicides	
Fumigants	Ovicides	

What is their nature? Most pesticides today are complex organic molecules either natural or man-made, though the latter greatly predominate. There is also a growing cadre of microorganisms that are successfully adding their weight to pest solutions. Pesticide classes and their characteristics are discussed in the coming pages.

The distribution of registered pesticide active ingredients by kind of use is shown in Figure 1-1. In the U.S., at the turn of the 21st century, there were approximately 900 pesticide active ingredients approved for use by the EPA. Between 1999 and 2002, EPA registered some 75 new active ingredients, more than half of which were conventional chemical products and most of the latter were "reduced risk" products.

FIGURE 1-1, Percent of Pesticide Active Ingredients by Use



These active ingredients are formulated into some 20,000 individual products. In California there are 925 pesticide active ingredients registered that comprise 11,947 individual products. California uses more pesticides than any other state largely because they have a great diversity and the largest share of crops that require pest protection. In later chapters we will elaborate on the nature of different major classes of pesticides.

Most of the pesticides currently registered with the EPA are detailed by category in Appendices C through F. The 25 most heavily used conventional pesticides in the U.S. during 1999 are listed in Table 1-2. Note that of these, 15 are herbicides, 3 are insecticides and 7 are fungicides and soil fumigants.

TABLE 1-2

Estimates of 1999 annual usage of the 25 most heavily used U.S. pesticides

Pesticide	Million Lbs Active Ingredient
1. Atrazine (H)	74-80
2. Glyphosate (H)	67-73
3. Metam Sodium (Fum)	60-64
4. Acetochlor (H)	30-35
5. Methyl Bromide (Fum)	28-33
6. 2,4-D (H)	28-33
7. Malathion (I)	28-32
8. Metolachlor (H)	26-30
9. Trifluralin (H)	18-23
10. Pendimethalin (H)	17-22
11. Dichloropropene (Fum)	17-20
12. Metolachlor-s (H)	16-19
13. Chlorothalonil (F)	9-11
14. Chloropicrin (Fum)	8-10
15. Copper Hydroxide (F)	8-10
16. Chlorpyrifos (I)	8-10
17. Alachlor (H)	7-10
18. Propanil (H)	7-10
19. EPTC (H)	7-9
20. Dimethenamid (H)	6-8
21. Mancozeb (F)	6-8
22. Dicamba (H)	6-8
23. Terbufos (I)	5-7
24. Ethephon (PGR)	5-6
25. Cyanazine (H)	4-8

Source: Donaldson et al, 2002.

Estimates do not include sulfur and petroleum oil usage

Pesticide category abbeviations: F, Fungicide; H, Herbicide; PGR, Plant Growth Regulator; Fum, Fumigant; I, Insecticide.

Overview of the pesticide industry—

Who makes pesticides? More than 118 U.S. firms manufacture pesticides of one kind or another, with only 18 accounting for the bulk of production and sales. Most of these 118 producers prepare one or more ready-to-use forms of their products and another 2,150 formulators throughout the U.S. prepare 20,726 different products for retail sales, which are sold by some 16,900 distributors. In 1999, an estimated 706 million lbs of conventional pesticides were used in the production of food, clothing and durable goods for the more than 272 million persons living in the U.S. or 2.96 pounds per person. Additionally, there are 33,100 commercial (structural) pest control firms, 803,423 certified private applicators, primarily individual growers and 384,092 certified commercial (professional) applicators (Donaldson, et. al., 2002). In 2003, there were an estimated 14,523 certified crop advisors and approximately 5,500 non-certified advisors, of whom some 1,400 are self-employed crop consultants. The states with the largest numbers of certified advisors are California (403), Illinois (1,514), Iowa (1,286), Texas (474), Nebraska (802), Minnesota (861), Ohio (643), Wisconsin (578), Missouri (438), Indiana (808) and Kansas (434). Canada has 1,139 certified crop advisors (Certified Crop Advisor Program 2003).

Size, value and distribution of the pesticide market— Pesticides are big business. The world market for pesticides is estimated at $33.59 billion, of which the U.S. represents the largest portion, in terms of dollars (33%) and lbs. of active ingredients (22%). Total U.S. pesticide usage was nearly 5 billion lbs of active ingredient. This includes conventional pesticides (912 million lbs), industrial wood preservatives (801 million lbs), sulfur, petroleum, sulfuric acid and other chemicals used as pesticides (332 million lbs), specialty biocides (342 million lbs) and chlorine and hypochlorites used in disinfection of potable and waste water (2609 million lbs). (See Figure 1.2). In 1999, the total U.S. expenditure for pesticides (not including wood preservatives, specialty biocides and chlorine/hypochlorites) was $11.2 billion which comprised 1.244 billion lbs (Donaldson, et. al., 2002). On their website (http://www.gcpf.org) Crop Life International reports the 2001 global sales of conventional products as being $25.76 billion (herbicides, 51.2%; fungicides, 19.4%; insecticides, 25.9%; and others, 3.5%). This site also shows the geographic distribution of conventional pesticide use in the world, based on dollars, to be: North America, 32.2%; Latin America, 16.6%; E. Asia, 22.7%; W. Europe, 19.9%; E. Europe, 4.1%; and remainder of the world, 4.7%.

Although U.S. domestic pesticide use has dropped from its peak of almost 1.2 billion lbs in 1979 to 912 million lbs in 1999 (Figure 1-3), the rest of the world until recently was using and manufacturing pesticides at an increasingly faster rate as more countries develop their agricultural and industrial economies. Thus, U.S. pesticide exports dropped from 737

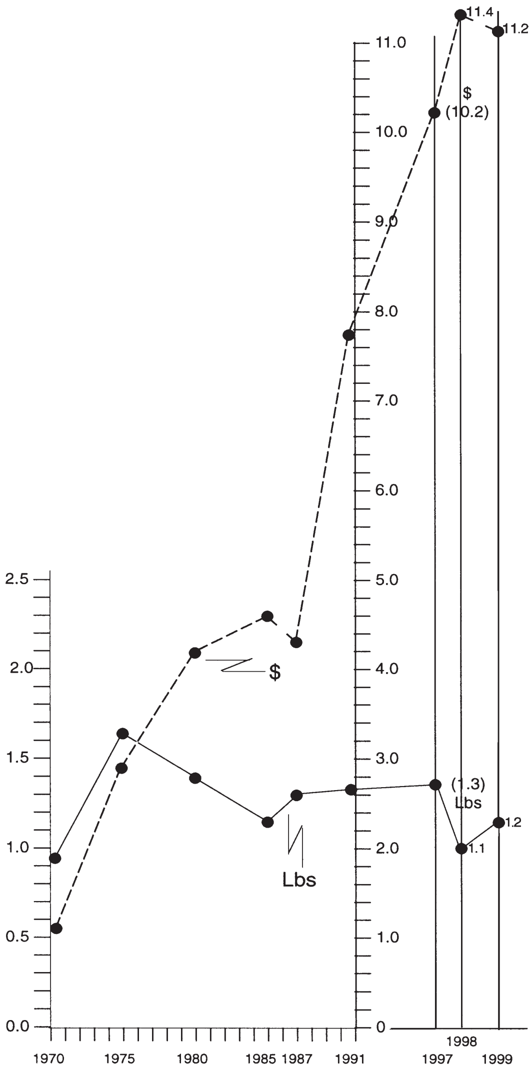
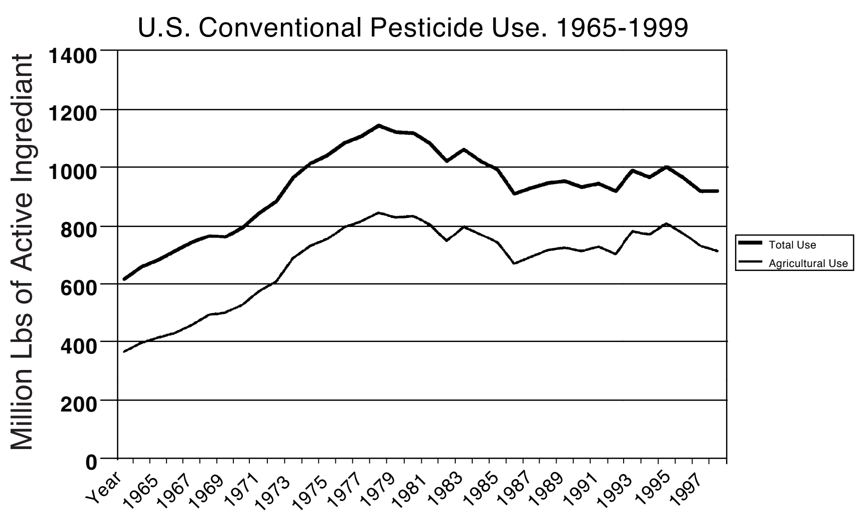


FIGURE 1-2

Production and sales of synthetic organic pesticides by the United States, 1970-1991.

(Source: Fowler and Mahan, 1980; Chemical & Engineering News, June 20, 1988; Dumas and Aspelin, 1988. Aspelin et al., 1992, Aspelin & Grube, 1998, Donaldson et al., 2002)

FIGURE 1-3



United States conventional pesticide usage: total and estimated agricultural sector share. 1964-1999. (Source; Donaldson et al., 2002) million lbs in 1980 (Storck, 1980), to 700 million lbs in 1999. Conversely, pesticide imports into the U.S. increased from 59 million lbs (valued at $175 million) in 1980, to 300 million lbs, valued at $1 billion, in 1999, an increase exceeding 500% (Donaldson, et. al., 2002). However, this trend has recently changed. Crop Life International reported a 7.4% global market decline in 2001 mainly because of low commodity prices which lowered farm income available to purchase pesticides. In 1999, the agricultural market consumed 77% of the conventional pesticides sold in the U.S. (Table 1-3). Industry and government used 14%, while home and garden consumption was only 9% (Donaldson, et. al., 2002). The industrial and commercial categories include applications of pesticides used by pest control operators, turf and sod producers, floral and shrub nurseries, railroads, highways, utility rights-of-way and industrial plant sites. Government use includes federal and state pest suppression and eradication programs and municipal and state health protection efforts involving the control of disease vectors such as mosquitoes, flies, cockroaches and rodents.

TABLE 1-3

Volume of Conventional U.S. Pesticide Active Ingredient Used by Class and Sector in 1999.

	Herbicides [1]		*Insecticides* [2]		*Fungicides* [3]		*Nematicides Fumigants*		*Other* [4]		*Total*	
	Million Pounds	*%*	*Million Pounds*	*%*	*Million Pounds*	*%*	*Million Pounds*	*%*	*Million Pounds*	*%*	*Million Pounds*	*%*
Agriculture	428	80	93	74	45	57	115	82	25	76	706	77
Ind., Comm. & Gov.	53	10	19	15	24	30	24	17	7	21	126	14
Home & Garden	54	10	14	11	10	13	1	1	1	3	80	9
Total	534	100	126	100	79	100	140	100	33	100	912	100

[1] Includes plant growth regulators
[2] Includes miticides
[3] Does not include wood preservatives
[4] Includes rodenticides, molluscicides and aquatic fish and bird pesticides but does not include wood preservatives,specialty biocides, chlorine/hypochlorites, and other chemicals used as pesticides like sulfur and petroleum
Source; Donaldson et al, 2002 (Based on Croplife America annual surveys, USDA/NASS (http://www.usda.gov/nass/), and EPA proprietary data)

The pesticide marketplace: history and future changes— Early producers of pesticides tended to have their core business in other areas, notably chemicals, pharmaceuticals or agricultural businesses linked to fertilizer. In the 1970s, when the industry was young, real global agrochemical market growth approached 8% a year. At that time there were about 25 significant pesticide producers who together accounted for about 90% of global pesticide sales. A decade later the average growth rate failed to reach 3% a year. This effect was primarily due to low crop prices, increasing government regulation and a maturing market. These new regulations and concomitant rising competition among survivors increased the costs of doing business including the cost of Research and Development (R&D). Competition also lowered profit margins which increasingly resulted in industry consolidation through a plethora of mergers and acquisitions (Appendix A). By 1990, annual growth rates had fallen below 3% and during the 90's they declined to near zero in real terms, which drove additional mergers in efforts to cut costs and retain selling margins. By 1998 there were only 10 major pesticide producers globally and these few accounted for about 80% of global sales.

As we start the 21st century, there are very few sizable market opportunities waiting to be exploited for conventional pesticide products. The cost of developing a successful new chemical active ingredient has grown from less than $5 million in the early 1960's to amounts approaching $50-100 million depending on uses and chemistry. Moreover, investments in conventional R&D have become very problematic. In the early 1960's fewer than 5000 experimental compounds on average were screened to yield a commercial product. In 2004, this number is in excess of 50,000 and perhaps much higher, despite advances made in directed chemical synthesis and greatly improved screening tools.

In conclusion, the pesticide industry in the U.S. and in other developed countries has become aged both technologically (chemical synthesis and screening) and commercially (filling market needs). There are few new market needs. However, there are both technological and market forces reshaping how the pesticide industry looks and does business. Market forces include rising competition and public demand for "safer" products. Technological forces include biotechnology and the advancements made in *precision agriculture* which, among other things, offers promise for reduced use while maintaining effectiveness of many pesticides. Biotechnology, which sprouted in the 1980's, is rapidly making inroads into the conventional pesticide markets by bringing new products and new ways to discover and deliver traditional products to the marketplace. We will elaborate on how biotechnology is changing conventional pest control practices in Chapter 24.

Pests and the damage they cause—

Pests on the home front—There are an estimated 104 million households in the U.S. (1999). In 1990, the Environmental Protection Agency (EPA) conducted a survey of 2,078 households in 29 states, on the use of pesticides in and around homes. An estimated 85% of all households had at least one pesticide stored at home. Most families had between one and five pesticide products and 27% of single-family households had more than six products. About 76% of households treated their homes themselves for insects and related pests, while 20% hired a commercial applicator to treat for pests such as fleas, roaches or ants. About 44% of all households identified at least one insect that was considered a major problem (Aspelin et al. 1992). Conventional pesticides were used by homeowners at about 74% of U.S. households in 1999 (Donaldson, et. al., 2002).

Householders depend on pesticides more than they perhaps realize: for algae control in the swimming pool, mildew control in the shower and laundry area and weed control in the yard. They use flea powder on pets, outdoor sprays to control a myriad of garden and lawn insects and diseases, indoor sprays for ants and roaches, aerosols for flies and mosquitoes. Soil and wood treatment offers termite protection, baits control mice and other rodents, woolen treatment provides moth protection and repellents keep biting flies, chiggers and mosquitoes off hikers and campers. Few homes in urban America are without some kind of pesticide spray, liquid, aerosol, paste, powder or cleanser, disinfectant or deodorizer. As expected, the homeowner pays more for his pesticides per unit of active ingredient than does agriculture or industry. The difference in price is mainly due to the specialized formulations used and the small quantities purchased. The average U.S. household in 1999 spent about $19 for pesticides applied by the homeowner. The average price per pound of pesticide active ingredient in 1999 was $24.80 for home and garden use, $12.27 for government and industry use and $10.80 for agricultural use (Donaldson et al. 2002).

Pests of plants— The world's main source of food is plants. They are susceptible to 80,000 to 100,000 diseases caused by viruses, bacteria, mycoplasma like organisms, rickettsias, fungi, algae and parasitic higher plants. They compete with 30,000 species of weeds the world over, of which approximately 1800 species cause serious economic losses. Some 3000 species of nematodes attack crop plants and more than 1000 of these cause severe damage. Among the 1,000,000 species of insects, about 10,000 plant-eating species add to the devastating loss of crops throughout the world. Of 10,000 farmers and ranchers surveyed in 1990, 88% reported wildlife damage to their crops or lands, some losing thousands of dollars annually. Two-thirds reported losses to deer, 36% to groundhogs, 17% to rabbits, 16% to mice and moles, 15% to beavers and 8% to migratory birds (Conover, 1991).

Approximately one-third of the world's food crops are destroyed by pests during growth, harvesting and storage. Losses are even higher in emerging countries: Latin America loses to pests approximately 40% of everything produced. Cocoa production in Ghana, the largest exporter in world, has been trebled by the use of insecticides to control just one insect species. Pakistan sugar production was increased 33% through the use of insecticides. The Food and Agriculture Organization (FAO) has estimated that 50% of cotton production in developing countries would be destroyed without the use of insecticides. In the U.S. alone crop losses due to pests are about 30% or $33 billion annually, despite the use of pesticides and other current control methods.

Cotton losses to insects: In 1995, before the introduction of transgenic Bt cotton (See *Glossary* for definition), losses to cotton insect pests were extensive, amounting to an estimated $1.6 billion. Losses were the combination of yield reduction of 2 million bales and control costs estimated at $880 million. Bales of cotton lost to the tobacco budworm and cotton bollworm were 785,000; boll weevil 341,000; beet armyworm, 287,000; lygus, 211,000; and aphids, 185,000. (Cotton Grower 1996).

In 1998, after the introduction of transgenic Bt cotton, losses were reduced to $1.2 billion, which included loss of only 1.7 million bales and costs of insect management, a 25% improvement for growers (California-Arizona-Texas Cotton, 1999).

What would the losses be without chemical controls? Studies were conducted in 1976-1978 to answer that question. Insecticides were used to control insects in test plots and the yields were compared with adjacent plots in which the insects were allowed to feed and multiply uncontrolled. From a single insect pest species, under severe conditions, each of the major crops suffered substantial losses, as Table 1 -4 shows. For example, 100% of the wheat in the untreated sample was destroyed by wheat mite.

TABLE 1-4

Comparison of losses caused by insects in plots treated by conventional use of insecticides and untreated plots.

Commodity	Calculated losses (percentage) With treatment	Calculated losses (percentage) Without treatment	Increased yield (percentage)
Corn			
Southwestern corn borer	9.9	34.3	24.4
Leafhopper on silage corn	38.3	76.7	38.4
Corn rootworm	5.0	15.7	10.7
Soybeans			
Mexican bean beetle	0.4	26.0	25.6
Stink bugs	8.5	15.0	6.5
Velvet bean caterpillar	2.4	16.6	14.2
Looper caterpillar	10.5	25.5	15.0
Wheat			
Brown wheat mite	21.0	100.0	79.0
Cutworms	7.7	54.7	47.0
White grubs	9.3	39.0	29.7
Cotton			
Boll weevil	19.0	30.9	11.9
Bollworm	12.1	90.8	78.7
Pink bollworm	10.0	25.5	25.5
Thrips	16.7	57.0	40.3
Potatoes			
Colorado potato beetle	1.0	46.6	45.6
European corn borer	1.5	54.3	52.8
Potato leafhopper	0.4	43.2	42.8

Source: *Washington Farmletter* (1979).

Equally important are the agricultural losses from weeds, the principal agricultural pests on most farms. Weeds deprive crop plants of moisture and nutritive substances in the soil. They shade crop plants and hinder their normal growth. They contaminate harvested grain with seeds that may be poisonous to humans and animals. In fact, over 700 plant species are known to induce illness in humans (Ziska, 2001). In some instances, complete loss of the crop results from disastrous competitive effects of weeds. Herbicide use on all field crops is now a well-established practice. Corn and soybeans together received 82% of all herbicides used in agriculture, while corn and cotton received 66% of all insecticides used in agriculture (Table 1-5) (Delvo & Hanthom, 1983).

In a study by the University of Illinois, the use of herbicides to control weeds in corn, soybeans and wheat was found to be economically essential. In this 10-year study (Table 1-6), the herbicide treatments increased average yields for corn and soybeans by roughly 20%. Wheat yields were not significantly affected. An economic analysis of these results indicated a rate of return on herbicide expenditures of about $4.00 for each $1.00 spent.

TABLE 1-5

Share of total agricultural herbicides and insecticides used in 1982 on corn, cotton, soybeans and wheat.

Crop	Share of pesticide used in agriculture (a.i.) Herbicides	Share of pesticide used in agriculture (a.i.) Insecticides
Corn	53.9	42.5
Cotton	3.8	23.9
Soybeans	27.7	15.4
Small grains (including sorghum)	8.6	7.2
Combined	94.0	89.0

(Delvo and Hanthorn, 1983)

TABLE 1-6
Increased yields of corn, soybeans and wheat in herbicide and crop sequence experiments from 1966 through 1975.

Crop sequence and treatment	*Average yield (bushels)*	*Percentage yield increase with herbicides*
Corn		
Continuous corn		
Conventional herbicide rotation	128.5	26.4
No herbicide treatment	101.7	
Corn & soybeans & wheat sequence		
Conventional herbicide rotation	138.9	21.9
No herbicide treatment	113.9	
Soybeans		
Corn & corn & soybeans sequence		
Conventional herbicide rotation	53.5	25.6
No herbicide treatment	42.6	
Corn & soybeans & wheat sequence		
Conventional herbicide rotation	54.9	23.6
No herbicide treatment	44.4	
Wheat		
Corn & soybeans & wheat sequence		
Conventional herbicide rotation	50.8	3.0
No herbicide treatment	49.3	

Source: Hawkins, Slife, and Swanson (1977).

Were it not for herbicides 8 to 10% of our farms would quickly become perpetuating weed fields that would require tremendous inputs of human energy to curtail. Indeed it has been estimated that more energy is expended worldwide on the weeding of crops than on any other single human task (Holm, 1971). Of the world's ten worst weeds, presented in Table 1-7, eight are grasses and five are perennials. The 10 worst weeds of the U.S. are listed in Table 1-8. All can be readily controlled with herbicides. As a point of interest, the two most widely used pesticides in 1999 were the herbicides atrazine and glyphosate, applied to corn and soybeans (Donaldson, et al., 2002).

Banning pesticide use could force the average consumer to pay an extra $228 per year for food, according to a study published by the National Chamber Foundation, the research-educational affiliate of the U.S. Chamber of Commerce. This would represent a 12% increase for middle-income consumers and a 44% increase for those on low incomes. The study also predicts that annual yields of wheat could fall by 24%; corn by 32%; cotton by 39% and rice by 57% (Anon, 1991). EPA estimated that in 1999, the use of conventional pesticides by U.S. farmers amounted to only 4.0% of total farm production costs (Donaldson, et al., 2002).

Economic and Quality of Life Losses: addressing the whims of nature—

Food and hunger— It is common knowledge that our current world food supply is inadequate. As much as 56% of the world's population is undernourished. The situation is worse in undeveloped countries, where an estimated 79% of the inhabitants are undernourished. The earth's

TABLE 1-7
The world's ten worst weeds.

Purple nutsedge (*Cyperus rotundus* L.)
Bermudagrass (*Cynodon dactylon* (L.) Pers.)
Barnyardgrass (*Echinochloa crusgalli* (L.) Beauv.)
Junglerice (*Echinochloa colonum* L.) Link
Goosegrass (*Eleusine indica* (L.) Gaertn.)
Johnsongrass (*Sorghum halepense* (L.) Pers.)
Cogongrass (*Imperata cylindrica* (L.) Beauv.)
Waterhyacinth (*Eichhornia crassipes* Mart.) Solms
Purslane (Common) (*Portulaca oleracea* L.)
Lambsquarters (Common) (*Chenopodium album* L.)

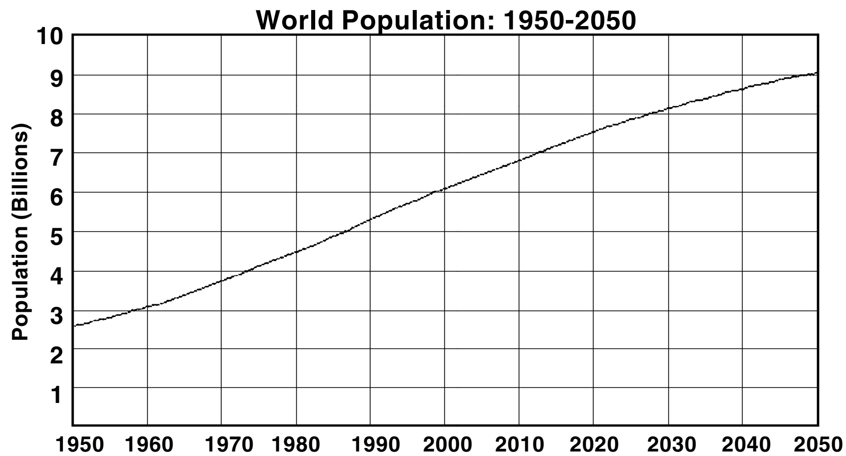
Source: Holm et al, (1999).

TABLE 1-8
The ten worst weeds of the U.S.[1]

Nutsedge spp. (Yellow, Purple) (*Cyperus esculentus, C. rotundus L.*)
Pigweed spp. (Smooth, Redroot) (*Amaranthus palmeri* Wats., *A. albus L.*)
Foxtail spp. (Giant, Green, Yellow) (*Hordeum leporinum, H. murinum*)
Morning-glory spp. (Annual, Tall) (*Ipomoea hirsutula* Jacq. f., I. *purpurea* (L.) Roth.)
Field Bindweed (*Convolvulus arvensis* L.)
Velvetleaf (*Abutilon theophrasti*)
Lambsquarters (Common) (*Chenopodium album* L.)
Canada Thistle (*Cirsium arvense*)
Johnsongrass (*Sorghum halepense* (L.) Pers.
Cocklebur (Common) (*Xanthium saccharatum* Wall)

[1] Source: Ag Consultant, March 1993, p 9.

FIGURE 1-4



Source: U.S. Census Bureau, International Data Base 10-2002

population was estimated at 3.6 billion in 1970, 4.4 billion in 1980, 5.0 billion in 1987 and reached 5.8 billion in 1997 and is estimated to reach 8.04 billion by the year 2025 (Figure 1-4). These numbers are not intended to evoke gloom about our ability to support such a population but to suggest that there will be great pressure to increase agricultural production, since this extra population must be fed and clothed. Each Asian farm worker produces an average of 44,000 lbs. of food crops each year, a Russian farm worker 33,000 lbs., a European farm worker 35,000 lb, yet each U.S. farm worker produces 374,000 lbs. While achieving this impressive production, the U.S. grows 48% of the world's corn and 63% of the world's soybeans. In the U.S. only 2% of the population is involved in agriculture, while only 8.7% of disposable income is spent for food (Table 1-9). In comparison, 17% of Russia's population is involved in agriculture and 38% of disposable income is spent for food.

TABLE 1-9

Percentage of population involved in agriculture and percentage of disposable income spent for food.

Country	*Percentage of population involved in agriculture* [a]	*Percentage of disposable income spent for food* [b]
United States	1.8[c]	8.7[d]
Australia	6.0*	14.5
United Kingdom	2.1*	11.9
France	9.1*	15.5
Japan	11.8*	20.8
Russia	17.3*	38.4
Brazil	38.9*	41.*
South Korea	39.9*	33.6
India	64.*	50.8
China	60.6*	48.

[a] Percentage of economically active population directly involved in agriculture, forestry, hunting and fishing.
[b] Includes expenditures for food consumed away from home.
Source: Food Review, U.S. Dept. of Agric., Ecomonic Research Service.
[c] Jan. - June 1992, for year 1990
[d] Sept. - Dec. 1996, for year 1993

TABLE 1-10

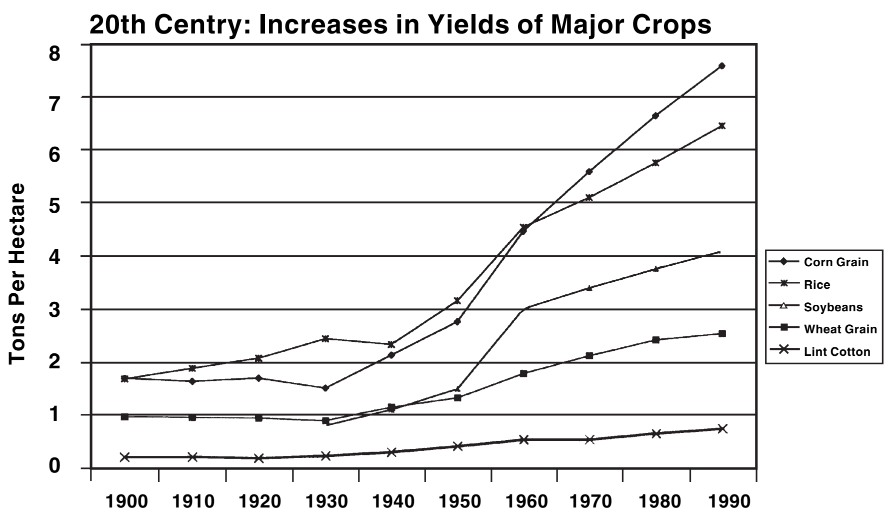
Increased production per acre of field crops grown in Arizona from 1950 to 1997.

Crop	*Yield per acre (short tons)* 1950	1997	*Increase (percent)*
Alfalfa hay	2.8	8.2	192
Wheat (Durham)	0.72	2.7	275
Barley	0.96	2.45	155
Grain sorghum	1.06	2.5	136
Corn, for grain	0.31	4.76	1,435

Source: Arizona Agricultural Statistics 1997 (July 1998)

The food production success of U.S. agriculture can be attributed to several factors, the more important of which are improved crop varieties, increased size and capacity of farm equipment, liberal use of fertilizers and extensive use of pesticides (Table 1-10). The best possible example is corn. In 1955 the national average for production was 42.0 bushels per acre. In 1994 that average had increased to 138.6 bushels or an increase of 230% (U.S.D.A. Agric Statistics, 1998) (Figure 1-5, Warren, 1998).

FIGURE 1-5



Pestilence and plagues—History offers innumerable examples of the mass destruction of crops by diseases and insects. The potato famine of Ireland occurred from 1845 to 1851, as a result of a massive infection of potatoes by a fungus, *Phytophthora infestans*, now commonly referred to as late blight. Either of two common fungicides, maneb or anilazine, would now control that disease handily with two or three applications. The famine resulted in the loss of about one million lives and mass migrations from Ireland to the U.S.

Surprisingly, the infected potatoes were edible and nutritious, but the superstitious population refused to use diseased tubers. In 1930, 30% of the U.S. wheat crop was lost to stem rust, the same disease that destroyed

3 million tons of wheat in western Canada in 1954. In 1988, wheat streak mosaic reduced Kansas wheat production by 13%.

Many kinds of animal and human disease are caused by organisms carried by insects. In 1991, five people contracted horse sleeping sickness (Eastern equine encephalitis) in Florida—the most since 1978—transmitted by a mosquito known as the Asian Tiger (*Aedes albopictus*) (Kunerth, 1992). In 1971, Venezuelan equine encephalitis appeared in southern Texas, moving in from Mexico. Through a very concerted suppression effort, involving horse vaccination, a quarantine on horse movement and extensive spraying for mosquito control, the reported cases were limited to 88 humans and 192 horses. With the other arthropod-borne encephalitides, there were an average of 205 human cases in the U.S. annually between 1964 and 1973. In the 19th century, the Panama Canal was abandoned by the French because more than 30,000 laborers died from yellow fever and malaria.

Since the first recorded epidemic of the Black Death or bubonic plague, more than 65 million persons have died from this disease, transmitted by the rat flea (*Nosopsyllus fasciatus*). In the U.S., bubonic plague is endemic to northern Arizona, northeastern California, southern Colorado and northern New Mexico, carried by fleas on prairie dogs that extensively colonize these areas. Infected fleas bite humans that come in close contact with these colonies, thus transmitting the disease, which may be fatal when not treated with appropriate antibiotics. Typically 2-3 deaths occur each year from the plague in these areas. Since 1947, there have been 390 cases of human plague in the U.S., resulting in 60 deaths (Centers for Disease Control and Prevention, 1997).

As late as 1955, malaria (transmitted from person to person only by female mosquitoes belonging to the genus *Anopheles*) infected more than 200 million persons throughout the world. The annual death rate from this debilitating disease has been reduced from 6 million in 1939 to 2.5 million in 1965 to about 1 million in 1991. The Centers for Disease Control and Prevention in Atlanta estimates that about 1,000 cases of malaria are imported into the U.S. annually, usually from travelers to Africa, Southeast Asia and South America (Rasche, 1992). Through the use of insecticides, similar progress has been made in controlling other important tropical diseases, such as yellow fever (transmitted by *Aedes aegyptii* mosquitoes), sleeping sickness (transmitted by tsetse flies in the genus *Glossina*) and Chagas' disease (transmitted by "kissing bugs" of the genus *Triatoma*). The number of deaths resulting from all wars appears paltry beside the toll taken by insect-borne diseases. Currently there is the ever-lurking danger to humans from such diseases as encephalitis, typhus, relapsing fever and sleeping sickness (Table 1-11).

TABLE 1-11
Some of the most common disease known to be transmitted to humans by insects, ticks or mites.

Disease	*Vector*
African sleeping sickness	Tsetse flies
Anthrax	Horse flies
Bubonic plague	A rat flea
Chagas' disease	Assassin bugs
Dengue fever	Two mosquitoes
Dysenteries	Several flies
Encephalitides	Several mosquitoes
Endemic typhus	Oriental rat flea
Epidemic typhus	Human louse
Filariasis	Several mosquitoes
Hemorrhagic fevers	Several mites and ticks
Leishmaniases	Psychodid flies
Louping ill	Castor bean tick
Lyme disease	*Ixodes* spp. ticks
Malaria	*Anopheles* mosquitoes
Onchocerciasis	Several black flies
Pappataci fever	A psychodid fly
Q fever	Ticks
Relapsing fevers	Several ticks
Rocky Mountain spotted fever	Two ticks
Scrub typhus	Chigger mites
St. Louis encephalitis	*Culex pipiens* mosq.
Trypanosomiasis	Several flies
Tularemia	Several flies, fleas, lice, ticks
West Nile Virus	Several mosquitoes
Yaws	Several flies
Yellow fever	Several mosquitoes

In recent years warm weather has brought recurrent news coverage of an insect-borne disease new to North America. First identified in 1933, in the West Nile River area of Africa, the West Nile Virus (WNV) first appeared in New York State in 1999 and now has spread over large portions of the U.S. In 2002, there were 3900 U.S. human cases of WNV which accounted for 247 deaths. The virus, which is believed to be spread by mosquitoes (the virus has been isolated from at least three dozen species), also infests and may be spread by birds, domestic livestock (mainly horses) and many different wildlife species. It is the most recent of a long history of diseases that are carried to humans and other species by pests (Illinois Agrinews, 1/24/2003).

Changing agricultural practices—

Conservation tillage and low input agriculture– Conservation tillage (minimum- no-tillage) or low input farming, is a growing farming practice that promotes energy savings and soil conservation by reducing or in some cases eliminating plowing and cultivation. Farmers once believed that fields required thorough plowing and in some instances cross-plowing, before new rows were made and the crop planted. In addition to energy and time savings, a principal motivation for making this change relates to its effect on dramatically reducing soil erosion from the effects of wind and water. With some crops, particularly corn, farmers now till only enough to plant the new crop, leaving most of last year's weed and crop debris remaining on the soil surface. Insecticides and herbicides play an important role in this method because the weeds and crop stubble provide a new source of weed seed and harborage for over wintering insects. The chemical control of the weeds and insects requires about 80% less energy than mechanical control by cultivation. Pesticides thus form the cornerstone of minimum tillage or no-till farming, a new agricultural concept for energy and soil conservation.

A rapidly developing tool for low input agriculture is the use of satellite data. Farm equipment manufacturers are increasingly selling global positioning satellite (GPS) equipment with information systems on tractors and combines that can precisely track conditions and can map the land to be tilled. Such equipment can direct a tractor operator to minimize overlap tillage or even map drainage, soil compaction or differential vegetation cover all of which may affect the choice of whether and how to till. Such equipment also offers prospects to greatly reduce the amounts of pesticides that are applied to achieve a target result.

Sustainable agriculture— Pesticide use in agriculture is increasingly coming under scrutiny in the context of preventing pollution and achieving a sustainable agricultural system. Several features of the practices now employed detract from agricultural sustainability over the long term. These include a heavy reliance on fossil fuels; cropping systems that degrade soils and water; monoculture cropping; chronically low economic returns that continue to force some farms, particularly family farms, out of business; and environmentally damaging accumulation of animal manures, inorganic fertilizers and pesticides or their residues.

The long-term solutions to such environmental and agricultural degradation, like the sources themselves, are highly diverse. But certain methods hold considerable promise. They include: rotating crops, monitoring routine economic levels of crop pests, avoiding "calendar systems" of pesticide application, using pest-resistant crop varieties, recycling animal manures as a partial substitute for inorganic nitrogen fertilizers and using biologically based methods of pest control (See Chapter 24, *Biorationals*). The overall objective of sustainable agriculture is to develop farming systems that emphasize environmentally benign practices while also sustaining yield and net farm income—agriculture that can be preserved for future generations.

Growth of Organic Agriculture– Organic and conventional farming are similar in many respects, but differ in their use of the products of modern chemical technology. Conventional farmers use synthetic chemical products while organic farmers avoid them. Instead, organic farmers use naturally occurring chemicals such as rock phosphate and limestone, manures produced by domestic animals, nitrogen derived from the atmosphere by leguminous (pea family) plants and substances with pesticidal properties that are produced by certain plants. Other "pesticides" sanctioned for use by organic growers include soaps (herbicidal and insecticidal), sulfur, oils and certain inorganic substances as insecticides and for plant diseases, several copper compounds, hydrogen peroxide, hydrated lime and antibiotics.

Conventional farmers use these chemicals as well as commercial fertilizers, synthetic pesticides, nutritional additives in animal feeds and animal drugs. Some people commonly use the word *organic* as a synonym for natural and regard organically grown food as nutritionally superior to conventionally grown food. Scientifically, natural substances are not necessarily organic and organic substances are not necessarily natural. As far as is known, conventionally grown plants are just as organic and just as nutritious as are organically grown plants and both absorb virtually all their supply of nutrients from the soil in inorganic forms.

Conventional and organic farming also differ in their use of energy. A 21-year study in Switzerland designed to compare conventional and organic plots indicated that yields in organic plots were 20% less than conventional plots, but had only 50% as much nutrient input. Also the organic systems consumed less energy by 20 to 50% (Maeder et al., 2002). Both conventional and organic farming are largely powered by fossil fuels, but conventional farmers use more energy per acre than do organic farmers because the production of synthetic fertilizers and pesticides requires fossil fuels. Fertilizers accounted for an estimated 33% of the total energy used in agricultural production in the U.S. in 1974 and pesticides accounted for 5 %. Since agricultural production consumed 3% of the total amount of energy used in the U.S., fertilizers and pesticides accounted for about 1% of the total energy used in this country. However, adopting organic farming methods would not decrease national energy consumption by 1%.

Additional land with lower yielding capability would have to be farmed to compensate for the lower yields obtained with organic farming. For example, the adoption of organic methods by farms now using a mixed grain-livestock system would result in decreased crop yields estimated at 15 to 25% per acre if there were little or no change in cropping pattern. If non-livestock farms were to adopt organic methods there would be a considerably greater decrease in total yield of the high-value crops, because the acreage of these would be reduced by introduction of legumes, which supply nitrogen, into the crop rotation. To offset such a 15% decline in yield, farmers would need to use 18% more of the same kind of land. But since the same kind of land is not available, any additional land would be less productive and more of it would be needed. Finally, if legumes were to become part of the cropping sequence on intensively cropped, nearly level land, more row crops would have to be planted on the sloping land to maintain the output; this would mean increased erosion (Council for Agricultural Science and Technology, 1980).

The latter portion of the 20th Century experienced a growing demand for organic produce, partly because of concerns surrounding levels of pesticide residues resulting from conventional farming. The fact that these residues are rarely above legal limits or that such residues also occur on organic produce, though less frequently and usually at lower levels, has done little to dissuade consumer preferences. In addition, organic produce consistently commands higher prices and is often marketed directly in roadside or local "farmers markets", which returns more money to the grower.

With increasing demand, a more diverse group of organic producers were looking for ways to formally label and make specific claims about the food they grew. This gave impetus for a push during the late 1990s to have the U.S. Department of Agriculture create a set of standards for growing organic foods, which thereby provide "certification" and allow consistent labeling or "branding" (in a marketing sense). Those standards provide for different classes of "organic". There are "100% organic", "organic" (inputs at least 95% organic) or "made with organic ingredients" (inputs at least 70% organic). After much and sometimes heated debate and after lengthy public comment periods, new organic standards were finalized by the U.S.D.A. and became effective in October 2002 [(www.usda.gov, www.ofrf.org) (Organic Farming Research)].

Benefits and risks of using pesticides—

Benefits and risks—What are the costs in terms of the effects on the environment, human health, wildlife, beneficial plants and insects and the safety of our food and feed crops if we continue to use pesticides at the current rate? We have seen the costs in the past three decades and will continue to see these penalties unless we reduce our dependence on pesticides as the single answer to pest control. As a society we must advocate specific, carefully planned utilization of pesticides integrated with other control measures.

Integrated pest management (IPM) is exactly that: The thinking man's pest control. IPM devises a workable combination of the best parts of all control methods applicable to a pest problem. IPM is the practical manipulation of pest populations using sound ecological principles to keep pests below economic injury levels. Pesticides are, however, an integral and indispensable part of IPM. They remain the first line of defense in pest control when crop injuries and losses become economic and they are the only answer to a severe pest outbreak or emergency.

The effects of pesticides on non-target organisms and the environment have been a source of worldwide contention for more than a decade and are the basis for most legislation intended to control or prohibit the use of specific pesticides. The most readily identified pesticide non-target consequences were those of the persistent organochlorine insecticides, such as DDT and their metabolites or conversion products on certain species of birds and fish. Consequences less readily identifiable include the effects of pesticide residues in food and the environment on humans and domestic animals. Ranging between these extremes are the unintentional effects of pesticides on plants, arthropod predators and parasites, soil microorganisms, wildlife, pollinating insects and soil- and water-inhabiting invertebrates.

Because of our inability to recognize all of the ecological relationships between target and non-target organisms we have made a few notable mistakes in the use of pesticides. Fortunately, however, these mistakes do not appear to have permanent or irrevocable consequences on non-target species.

The benefits of pesticides are many. These chemical and biological tools are used as intentional additions to the environment to improve life quality for ourselves, our animals and our plants. In agriculture, pesticides are essential tools. Like the tractor, mechanical harvester, electric milker and fertilizers, pesticides are part of modern agricultural technology. Farmers use pesticides to increase productivity, a benefit that favors the grower and, ultimately, the consumer of food and fiber products—the public.

Pesticides have contributed significantly to the increased productivity of American farmers. In 1776 each farmer produced enough food and fiber for 3 people; in 1950, enough for 14 people; in 1981 enough for 78; in 1990 enough for 96 and in 1999, for well over 100 (Figure 1-6).

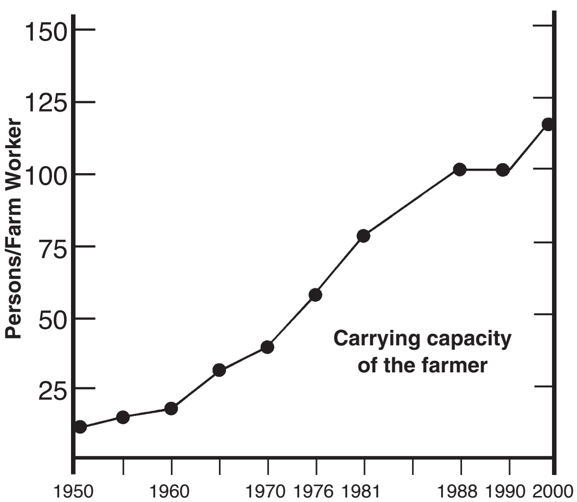


FIGURE 1-6
Persons supplied farm products per farmer. 1950-2000.
(Source: U.S. Department of Agriculture, 1992. Production & Efficiency Statistics 1990).

It is estimated that insects, weeds, plant diseases and nematodes account for losses of up to $33 billion annually in the U.S. alone. The use of pesticidal chemicals in agriculture enables farmers to save approximately an overall one-third of their crops. Because of the economic implications of such losses and savings pesticides have assumed major importance. Figure 1-5, provides graphic evidence of how yields of major crops increased during the 20th Century (Warren, 1998).

What is the balance?—Pesticides have long been steeped in controversy. The two factors that may contribute most to this state are that pesticides are deliberately designed to be toxic to their target pest or pests and people intuitively understand that such agents are or may be toxic to them. The second factor, as we have enumerated above, is that pesticides were often not safely used in the early decades of their existence. This has led to well remembered disasters which begged for remediation. In the succeeding decades changes in pesticide types, characteristics, practices and overall safety have truly been revolutionary. Such changes continue even as we begin this new century.

On the favorable side of any balance sheet is the degree to which the research done during their discovery, development and registration paints a dependable picture of a pesticide's favorable and particularly its unfavorable characteristics. Today, if a pesticide is registered by the U.S. EPA and by the states within whose borders it will be used, it is virtually always safe when used according to the label. Only pharmaceuticals, which have the advantage of being tested directly in humans as part of the process to determine their therapeutic effectiveness, are better tested before they are sold in the market place.

On the other side of the equation is the immutable truth that no product is totally safe regardless of its nature or depth of testing. Given the genetic diversity of human populations and the fact that for ethical reasons tests for human safety are performed on experimental animals, one must extrapolate results to humans with considerable caution. It is comforting that the laws under which EPA acts to register pesticides take such extrapolation and its sensitivities into consideration. In particular, rather large safety factors of at least two orders of magnitude are built in to levels that are deemed safe for humans (i.e.- if 1 mg/kg fed chronically to a rat is entirely safe for the rat, then the maximum that humans can legally be exposed to is no more than 1/100th of this amount and usually less). Still from grim experience we know that humans, including the young, aged and sick may have profiles that render them particularly sensitive or given to idiosyncratic responses. As in other human endeavors, the buyer and user must take care to understand risks and act responsibly when applying a pesticide.

One of the most important acts of a pesticide user is to first, read and understand the label before using any product and second to be somewhat critical of any information that deviates from the label unless it comes from federal or state regulators or informed state agricultural or urban scientists.

Today, one and usually multiple products are available to control every pest. For this reason many people wonder why newer or different pesticides are necessary. The fact is that pest susceptibility and the particular nature of pests that infest various crops or livestock is a dynamic rather than static process. New pests can be and are imported or arise or change their nature. As a consequence of this and in all prudence, we must have an assortment of tools in the arsenal with the hope that new emergencies that arise can be addressed with one or more of our current products, new practices or an integration of these.

More information? The www awaits your pleasure—

In this first chapter, we have introduced a number of topics in an effort to orient the reader to the topic of pesticides. We will elaborate on many of these areas in coming chapters. Although the references and bibliography at the end of this book may be useful to those interested in delving more deeply into the topics covered (or not covered), the Worldwide Web is often the first place the student may gravitate. For this reason we have incorporated and refer you to Appendix B, which is specifically designed to provide a stepping stone to those who are on the prowl for more pesticide information. The listing we provide is certainly bare bones in the sense that any search with an effective browser may generate hundreds or even thousands of websites. The ones listed are those with which we have some acquaintance and which are likely to be reliable.

Although we do recommend that you use the Web as key information source, we would also draw your attention to the unfortunate fact that, unlike peer reviewed journals available in your science libraries, many websites often represent a particular point of view. This is especially true where opinions and interpretations are being given rather than referenced data or “factual information”.

In general, a good place to begin any search for pesticide information is with the governmental sites, including Federal, State and University Extension sites. There are also a number of organizations and institutions listed that are often good places to obtain information on pesticides.