Article

Global pesticide consumption and pollution: with China as a focus

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Abstract
Varieties and consumption of pesticides worldwide have been increasing dramatically as increased human population and crop production. In this process pesticide misuses become more and more serious, which has resulted in heavy environmental pollution and health risk of humans. In order to safeguard human health, threatened species and ecosystems from pesticide pollution, the consumption and pollution of pesticides worldwide especially China were reviewed and documented in present study. Meanwhile, the development trend of pesticide varieties and consumption was also prospected and discussed. It was found that worldwide consumption structure of pesticides has undergone significant changes since 1960s. The proportion of herbicides in pesticide consumption increased rapidly and the consumption of insecticides and fungicides/bactericides declined. China has become the largest pesticide producer and exporter in the world. Pesticide pollution of air, water bodies and soils, and pesticide-induced deaths in China has been serious in past years. Bio-pesticides should be further developed in the future.

Keywords pesticides; consumption; pollution; world; review.

1 Introduction

1.1 Definition of pesticide

A pesticide is any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest (insects, mites, nematodes, weeds, rats, etc.), including insecticide, herbicide, fungicide, and various other substances used to control pests (EPA, 2009). Definition of pesticide varied with times and countries. However, the essence of pesticide remains basically constant, i.e., it is a (mixed) substance that is poisonous and efficient to target organisms and is safe to non-target organisms and environments.

1.2 History of pesticide production and application

The history of pesticides can be divided into three phases (Zhang et al., 2001): (1) in the first phase (the period before 1870s) natural pesticides, for instance sulfur in ancient Greece, were used to control pests; (2) the second phase was the era of inorganic synthetic pesticides (the period 1870s-1945). Natural materials and inorganic compounds were mainly used during this period; (3) the third phase (since 1945) is the era of organic synthetic pesticides. Since 1945, the man-made organic pesticides, e.g., DDT, 2,4-D, and later HCH, dieldrin, have terminated the era of inorganic and natural pesticides. Since then most pesticides have been synthesized by humans, and they were named chemical pesticides. The application of chemical pesticides, in particular the organic synthesized pesticides has been a significant mark of human civilization, which greatly protects and facilitates agricultural productivity.

In the earlier period of organic synthesized pesticides, there were mainly three kinds of insecticides, carbamated insecticides, organophosphorus insecticides and organochlorined insecticides. Sooner after that herbicides and fungicides achieved a considerable development as well. The consumption of insecticides is estimated to decline gradually and the use of herbicides would be popular in the future. This trend may be found from the changes of the structure of pesticide consumption worldwide (Table 1).

Table 1 Changes of pesticide consumption worldwide

Category	1960		1970		1980		1990		2000		2005	
	Sale	%	Sale	%	Sale	%	Sale	%	Sale	%	Sale	%
Insecticides	310	36.5	1002	37.1	4025	34.7	7655	29	7559	27.9	7798	25.0
Herbicides	170	20.0	939	34.8	4756	14.0	11625	44	12885	47.5	14971	48.0
Fungicides & Bactericides	340	40.0	599	22.2	2181	18.8	5545	21	5306	19.6	7486	24.0
Others	30	3.5	159	5.9	638	5.5	1575	6	1354	5.0	936	3.0
Total	850	100	2700	100	11600	100	26400	100	27104	100	31191	100

Sale: million US dollars (Xu, 1997; http://www.docin.com/p-55305172.html)

As can be seen from Table 1, worldwide consumption structure of pesticides has undergone significant changes since 1960s. The proportion of herbicides in pesticide consumption increased rapidly, from 20% in 1960 to 48% in 2005. The proportion of consumption of insecticides and fungicides/bactericides declined despite their sales increased. The rapid increase of herbicide consumption enhanced agricultural intensification and productivity.

1.3 Benefits and risks of pesticide application

Worldwide approximately 9,000 species of insects and mites, 50,000 species of plant pathogens, and 8,000 species of weeds damage crops. Insect pests cause an estimated 14% of loss, plant pathogens cause a 13% loss, and weeds a 13% loss (Pimentel, 2009a). Pesticide is so indispensable in agricultural production. About one-third of the agricultural products are produced by using pesticides (Liu et al., 2002). Without pesticide application the loss of fruits, vegetables and cereals from pest injury would reach 78%, 54% and 32% respectively (Cai, 2008). Crop loss from pests declines to 35% to 42% when pesticides are used (Pimentel, 1997; Liu and Liu, 1999).

In view of the world’s limited croplands and growing population (Zhang et al., 2006; Zhang, 2008), it is necessary to take all measures to increase crop production in order to ensure food safety (Zhang et al., 2007, 2008c; Zhang, 2009). Knutson and other researchers pointed out that if the consumption of pesticides is prohibited, the food production in USA would drop sharply and the food prices would soar. In this circumstance, the export of cotton, wheat and soybean in the United States would decline by 27%, and 132,000 jobs would be lost. Fungicides are used to 80% fruit and vegetable crops in the United States. The economic value of the apple has increased 1,223 million dollars by using fungicides (Guo et al., 2007).

Meantime, the risks of using pesticides are serious as well (Pimentel, 2009b). Most pesticides are not spontaneously generated. Most of them are high toxic to humans and the environment. Pesticides and their degraded products would flow into the atmosphere, soils and rivers, resulting in the accumulation of toxic substances and thus threatening human health and the environment.

On an international symposium for safety management strategy of foods and agricultural products, held in

Hangzhou in 2008, Gero Vaagt pointed out that there were four aspects of issues in pesticide production and application worldwide: (1) some countries still produced or used highly toxic pesticides; (2) pesticides were overused to a variety of crops like cotton, vegetables and rice; (3) the quality of pesticides was poor, for instance, some countries were not able to effectively regulate pesticides and thus result in the production and consumption of counterfeit and unqualified pesticides, and (4) pesticide residue standards were not implemented effectively.

The environmental pollution caused by pesticides in Asia, Africa, Latin America, the Middle East and Eastern Europe are now serious. Even in earlier years the residuals of DDT, lindane and dieldrin in fish, eggs and vegetables have been much beyond the safe range in India (Wu, 1986). In India the DDT content in human body was ever the highest in the world.

2 Worldwide Production and Consumption of Pesticides

Over 1990s, the global pesticide sale remained relatively constant, between 270 to 300 billion dollars, of which 47% were herbicides, 79% were insecticides, 19% were fungicides/bactericides, and 5% the others (Table 1). Over the period 2007 to 2008, herbicides ranked the first in three major categories of pesticides (insecticides, fungicides/bactericides, herbicides). Fungicides/bactericides increased rapidly and ranked the second. Europe is now the largest pesticide consumer in the world, seconded by Asia. As for countries, China, the United States, France, Brazil and Japan are the largest pesticide producers, consumers or traders in the world.

Most of the pesticides worldwide are used to fruit and vegetable crops. In the developed countries pesticides, mainly herbicides, are mostly used to maize.

Since the 1980s hundreds of thousands of pesticides have been developed, including various biopesticides.

2.1 United States

It can be found from Table 2 that pesticide export of the United States was greatly higher than its import. In 2006 the import (export) of herbicides of the United States made up 45.4% (51.6%) of its total import (export). Maize and soybean pesticides occupied most of the pesticide markets (Table 3), totally making up 44.75% of the pesticide sale in 2007, of which pesticide consumption of maize was about 2 times that of soybean. 75.3% of pesticides used to maize were herbicides, seconded by insecticides. The consumption of fungicides/bactericides on maize roared in 2007, from 6 million US dollars in 2005 to 130 million US dollars in 2007. For soybean, herbicides were dominant pesticides.

Atrazine held the highest portion in the maize herbicides. In 2005 its consumption reached 57.39 million pounds, almost twice as much as glyphosate. The tefluthrin and cyfluthrin constituted the largest consumption to maize in the United States, third by tebupirimfos. Acetochlor and s-metolachlor were the popular maize herbicides after glyphosate. Meanwhile, mesotrione was used to 20% of maize production as well.

Table 2 Import/export of pesticides of some major countries in recent years

Import/Export	Category	Country	2000	2001	2002	2003	2004	2005	2006
Import (US$1,000)	Pesticides	USA	471168	652447	501627	637199	748955	724882	655367
		Germany	600541	520461	621947	712762	840315	1000303	975375
		France	1387807	1173452	1287594	1426783	1678545	1774133	1462328
		Japan	269655	263994	249008	243039	266196	296083	314592
		Australia	198139	186483	185323	196401	265128	284037	284262
		S. Africa	102876	91625	98001	126321	153665	150407	170051
	Insecticides	USA	82745	189048	85145	96949	124736	128625	117246
		Germany	50643	48162	72745	91353	91877	100059	85380

		France	241043	197565	214614	268206	294944	288445	262503
		Japan	43354	54883	63338	54977	59250	86152	95660
		Australia	63723	53107	38842	29914	54472	66404	66455
		S. Africa	40511	38461	42076	51718	68804	65321	67586
	Fungicides	USA	146313	143318	145534	179533	236757	244226	152301
		Germany	276210	214278	201054	240257	243189	335761	309141
		France	473119	432035	547272	571386	590383	712551	459202
		Japan	108963	104133	85115	95366	99191	90831	91848
		Australia	32861	30016	31105	39747	41732	54375	53763
		S. Africa	20569	20017	18963	24828	31235	31822	37947
	Herbicides	USA	213485	291233	236100	310730	304715	282872	298059
		Germany	217369	195114	270169	275636	359263	417922	436314
		France	570623	459998	433102	482940	682198	657921	595424
		Japan	105558	94186	88759	82304	98119	109464	117621
		Australia	79150	82267	92598	92648	129822	132367	133878
		S. Africa	35131	27514	32250	43253	46543	45031	55698
	Disinfectants	USA	28625	28848	34848	49987	82748	69160	87761
		Germany	56319	62906	77979	105516	145986	146561	144540
		France	103023	83855	92606	104251	111021	115216	145200
		Japan	11781	10792	11797	10392	9636	9635	9463
		Australia	22405	21093	22778	34091	39102	30891	30166
		S. Africa	6666	5633	4712	6522	7082	8233	8820
Export (US$1,000)	Pesticides	USA	1492417	1547475	1547202	1457495	1721760	1621195	1906288
		Germany	1858538	1401648	1552426	1805560	1822556	1908079	2355308
		France	1700933	1473243	1601636	1858499	2633837	2566852	2477606
		Japan	274765	253749	239955	269034	297725	309338	314931
		Australia	52667	52237	70644	72498	73865	72166	66328
		S. Africa	109578	121796	105979	133625	153540	143139	131585
	Insecticides	USA	423215	407252	445570	431467	501799	373460	468545
		Germany	293326	204768	209430	270766	286096	289008	339146
		France	388332	332709	333485	397697	536944	492160	416590
		Japan	107558	98016	94573	107266	116777	118846	136715
		Australia	18064	24482	33691	33294	23360	25668	18742
		S. Africa	29805	28032	28671	35529	36583	42083	48425
	Fungicides	USA	155674	142257	172466	220980	274667	258393	286200
		Germany	609388	500089	559770	595337	738597	737897	745524
		France	516724	416907	498057	554133	767753	885303	779649
		Japan	75981	68552	70863	74210	78392	78057	72614
		Australia	2933	2434	5667	7038	9645	10882	13803
		S. Africa	18400	16340	11463	13681	16024	22307	21860
	Herbicides	USA	779936	837017	790926	647111	777829	837163	983249
		Germany	719662	483870	530916	614290	434823	507688	833748
		France	741932	666562	704590	827634	1225871	1069496	1144222
		Japan	83809	81096	64424	74287	86315	96908	91909
		Australia	26638	21324	22911	22909	32347	29361	25252
		S. Africa	57109	70013	59766	77313	94808	70730	51125

	Disinfectants	USA	133592	160949	138240	157938	167465	152179	168294
		Germany	236162	212920	252310	325167	363040	373486	436890
		France	53945	57064	65504	79035	103269	119894	137146
		Japan	7416	6085	10096	13272	16241	15527	13694
		Australia	5031	3996	8376	9256	8512	6254	8530
		S. Africa	4264	7410	6078	7102	6126	8020	10175

Data from FAO (2010)

Table 3 Pesticide sales in the United States in 2005 and 2007 (million US dollars)

Crop	2005				2007			
	Herbicides	Insecticides	Fungicides & Bactericides	Total	Herbicides	Insecticides	Fungicides & Bactericides	Total
Maize	1239	338	6	1583	1385	320	130	1835
Fruits/Vegeta.	369	486	393	1248	369	468	314	1151
Potato	34	84	49	167	19	107	62	188
Grape	40	35	53	128	32	48	32	112
Pear	30	57	36	123	43	28	27	98
Others	265	310	255	830	275	285	193	753
Soybean	811	3	60	874	730	85	65	880
Cotton	269	178	6	453	200	180	3	383
Cereals	390	42	40	472	390	40	37	467
Rice	115	8	25	148	82	5	18	105
Beet	70	13	11	94	72	14	10	96
Sunflower	40	8	0	48	35	6	0	41
Sugarcane	32	6	0	38	28	5	0	33
Rape	12	2	0	14	13	2	0	15
Others	778	225	175	1178	610	120	55	785
Total	4125	1309	716	6150	3914	1245	632	5791
Percent (%)	67.1	21.3	11.6	100	67.6	21.5	10.9	100

Data from Bo and Zhang (2009)

Pesticide consumption has been reducing in the United States to protect the environment. As early as in 1972, the uses of DDT and related organochlorinated insecticides were banned in the United States. During the late 20th century, pesticide consumption in the United States declined by 35% without reducing crop production (SDNX, 2005).

2.2 Europe

Germany is the largest producer and second largest consumer of pesticides in Europe. France is the largest pesticide consumer in Europe, followed by Germany (Table 4). Other major pesticide consumers in Europe include Italy, Spain and UK.

2.2.1 Germany

According to historical records, herbicides dominated the pesticide markets in Germany. In 2006, Germany exported herbicides worth of 830 million US dollars. Consumption of herbicides is the largest (Table 2, 5).

Table 4 Pesticide sales in some European countries (million US dollars)

Country	2006	2007	Increase (%)
France	2424.2	2564.3	5.8
Germany	1566.7	1737.2	10.9
Italy	1003.6	1043.3	4.0
Spain	782.9	810.4	3.5
UK	686.4	770.7	12.3

Data from ECPA (http://www.ecpa.be/)

Table 5 Consumption of pesticides of some major countries in recent years (tons)

Category	Country	2000	2001	2002	2003	2004	2005	2006	2007
Insecticides	Germany	1380.4	1308.7	1412.3	1038.1	1201.7	963.31	776.24	1370.4
	France	3103	2488	2308	2224	2460	2506	2140	2101
	Japan	27292.3	26227.3	23363.1	24795.1	22772.5	22679.6	24031.8	22549.0
Herbicides	Germany	16610.8	14942.2	14327.9	15349.5	15922.9	15610.3	17062.8	17163.7
	France	30845	32122	28779	24508	26102	29209	23068	26808
	Japan	11331.7	11793.1	11492.8	10942.4	11861.5	12158.1	11946.7	12031.6
Fungicides & Bactericides	Germany	9375.9	8021.9	9915.8	9827.4	7858.4	9543.2	9523.4	10311.7
	France	52834	54130	43351	39317	37175	35921	35957	36919
	Japan	40611.9	39993.2	34768.5	31521.0	29582.8	28526.2	28850.7	26199.0

Data from FAO (2010)

It is believed that the domestic market tends to be saturated and the export increases. In 2008 the export to Central America and South America increased by 10%. However the export to Europe declined.

2.2.2 France

Fungicides/Bactericides are the most used pesticides in France (Table 2, 5). In total 36,919 tons of fungicides, 2,101 tons of insecticides and 26,808 tons of herbicides were consumed during 2007. The pesticide sale in 2008 increased by 13.3% and the sale reached 2.959 billion US dollars. The sale of fungicides roared by 16.5% in 2008 (Lan and Bo, 2009).

Overall the pesticide consumption in Europe declined in last decades. The consumption declined by 50% compared to the average in 1980s.

2.3 Asia

2.3.1 China

According to a report, there are 1,648 kinds of agricultural pests in China, including 724 plant diseases, 838 insects (mites), 64 weeds, and 22 rodents. Without pesticide uses, the production of fruits, vegetables and cereals will lose 78%, 54% and 32% respectively (Cai, 2008). Pesticide uses in China reduce the loss of 89.44 million tons of cereals, 1.65 million tons of cotton, 2.53 million tones of oilseeds and 78 million tons of vegetables (Editorial Board of Chinese Yearbook on Agriculture, 2007).

China is one of the earliest countries to use pesticides. As early as in Ming Dynasty, the monograph *Ben Cao Gang Mu*, edited by Li Shizhen, has recorded a number of plants and minerals that used as pesticides such as veratridine, flavescens, arsenolite, realgar, orpiment and lime, etc (Chen, 2007). China started to manufacture HCH in 1950. In 1957 the first factory in China, producing organophosphorus pesticides, was built. During 1960s to 1970s, China mainly manufactured organochlorined, organophosphorus and carbamated pesticides. Since 1983 China has increased the production of organophosphorus and carbamated pesticides. Meanwhile pyrethroid and other pesticides were developed (Lin et al., 2000). Since 1994 pesticide export of China has exceeded its import. So far, there are more than 2,000 pesticide companies, of which more than 400 companies are manufacturers for original pesticides; more than 300 varieties of original pesticides and 3,000 preparations are being manufactured. China's pesticide production has reached 1.73 million tons (Zhu, 2008). China is now the largest producer and exporter, and the second largest consumer of pesticides in the world (Rajinder et al., 2009).

China has banned the application of high-residual HCH, DDT and other organochlorined pesticides since 1983. Since 2007, the high-poisonous organophosphorus pesticides, parathionmethyl, parathion, methamidophos, and phosphamidon have been banned for using and selling in China.

In China, rice is the major crop to consume pesticides. Rice pesticide sale, accounting for 15% of total sale, reached 538 million US dollars in 2006. Vegetable pesticide sale made up 24.2% of total sale.

According to the data from China Custom (Table 7; Lan and Bo, 2009), during 2008 China imported 44,000 tons of pesticides (300 million US dollars); exported 55,000 tons of fungicides (240 million US dollars), an increase of 5.2% against the export in 2007; exported 136,000 tons of insecticides (510 million US dollars), declining by 1.9%; exported 277,000 tons of herbicides (1.23 billion US dollars), increasing by 5.1%. In general, herbicides accounted for the greatest portion of the total export.

Table 6 Pesticide production, consumption and import/export of China (10,000 tons)

Year	Production	Consumption	Import	Export
1983	33.1		6.1	
1984	29.9		5.9	
1985	21.1		1.6	
1986	20.3		0.7	
1987	16.1		1	
1988	17.9		3.4	
1989	20.8		3.7	
1990	22.8		2.8	
1991	25.5	76.1	3.2	
1992	28.1	79.5	3.9	
1993	25.7	84.9	2.3	4.2
1994	29	87.1	3.1	6.1
1995	41.7	108.7	3.4	7.1
1996	42.7	114.1	3.2	7.4
1997	55.2	119.5	4.8	8.8
1998	60.5	123.2	4.4	10.7
1999	62.5	131.2	4.7	14.7
2000	60.7	128	4.1	16.2
2001	78.7	127.5	3.4	19.7
2002	92.9	131.2	2.7	22.2
2003	76.7	132.5	2.8	27.2
2004	87	138.6	2.8	39.1
2005	104	146	3.7	42.8
2006	129.6		4.3	58.3
2007	173.1			
2009	220.0			

Data from Ministry of Agriculture of China (http://www.stats.gov.cn/)

Table 7 Import/export of pesticides of China in 2008

Category	Import (million US dollars)		Import (1,000 tons)		Export (million US dollars)		Export (1,000 tons)	
	2008	Growth %	2008	Growth %	2008	Growth %	2008	Growth %
Insecticides	60	14.8	8	11.1	510	24.4	136	-1.9
Herbicides	110	35.7	19	5.0	1230	72.2	277	1.8
Fungicides & Bactericides	100	20.8	13	-2.7	240	38.3	55	5.1
Total	300	27.6	44	7	2020	49.7	485	1.5

Data from CCPIA (www.ccpia.org.cn/)

2.3.2 Japan

Japan is one of the world's largest pesticide consumer and the largest pesticide market in Asia (Table 2, 5). Japan has banned the consumption of DDT, HCH, organomercury fungicides/bactericides and parathion since 1971 (Wu, 1985). However Japan's pesticide export to China and Southeast Asia countries is continuously increasing. In Japan, pesticides are mainly used to rice, and are being increasingly used to horticultural crops (Table 8). Consumption of rice pesticides accounted for 41% of the total. The consumption of insecticides is still the greatest but the sale of herbicides ranks the first (Table 2, 5, 8). Among herbicides glyphosate products are popularly applied. Most of insecticides and fungicides/bactericides are applied to vegetable crops and most of herbicides applied to rice.

Table 8 Pesticide sale in Japan during 2004-2007

Crop	Category	04/05 Sale		05/06 Sale		06/07 Sale	
		Tons	Million J Yen	Tons	Million J Yen	Tons	Million J Yen
Rice		98670	118979	94858	118220	85894	112815
	Insecticides	23336	14615	23446	15309	20641	13771
	Fungicides & Bactericides	15695	17837	14366	15981	12272	14509
	Herbicides	34798	54841	33526	55513	32528	55160
Fruits		24104	56622	22619	53031	21708	52030
	Insecticides	11179	26454	11003	24676	10627	25104
	Fungicides & Bactericides	7943	19618	7059	18785	7085	18970
	Herbicides	4923	10452	4516	9509	3960	7899
Vegetables		89634	110467	88616	113036	82609	114214
	Insecticides	49298	54714	48826	55725	44244	55921
	Fungicides & Bactericides	28230	37124	27606	37288	26739	40784
	Herbicides	11190	18045	11187	19368	10770	16873
Others		15706	30866	17749	34001	15830	34001
	Insecticides	40822	6171	4044	6309	2541	5375
	Fungicides & Bactericides	1076	5130	1298	6541	1194	7276
	Herbicides	10172	19286	10502	20007	10492	16833

Data from JCPA (www.jcpa.or.jp/)

2.4 Australia

Australia's pesticide import is greatly larger than the export (Table 2). Herbicides accounted for 47% of the total import in 2006. Of the pesticides imported, the products from China are quickly increasing, including glyphosate, paraquat and glufosinate-ammonium. About 10% of glyphosate are from China. Endosulfan from China is the major cotton insecticide and acaricide in Australia.

2.5 South Africa

Pesticide consumption of Africa accounts for about 3% of the world, of which South Africa makes up 2% of pesticide consumption of the world (Table 2). As the development of Africa's agriculture, pesticide production of South Africa is expected to grow rapidly in the future.

3 Worldwide Situation of Pesticide Pollution

Globally 4.6 million tons of chemical pesticides are annually sprayed into the environment. There are currently about 500 pesticides with mass applications, of which organochlorined pesticides, some herbicides and the pesticides containing mercury, asenic and lead are highly poisonous to the environment. Only 1% of the sprayed pesticides are effective. 99% of pesticides applied are released to non-target soils, water bodies and atmosphere, and finally absorbed by almost every organism.

According to a report from the EPA of the United States, many of rural wells in the nation contain at least one of 127 pesticides. A research panel of Indiana University analyzed barks from 90 sites from the equator to high latitude cold regions, and detected DDT, aldrin and lindane residuals. High-residual pesticides like DDT have been detected in the Greenland ice sheet and the bodies of Antarctic penguins which were resulted from atmospheric circulation, ocean currents and biological enrichment of pesticides.

According to a report of WHO and UNEP, worldwide there are more than 26 million human pesticide poisonings with about 220,000 deaths per year (Richter, 2002). In the United States, there are 67 thousands human pesticide poisonings per year. In China, there are 0.5 million human pesticide poisonings with 0.1 million deaths per year.

Table 9 Application dosage of chemical pesticides in China (kg/ha)

Dosage level	Province or city	Dosage	Dosage level	Province or city	Dosage
Ⅰ	Shanghai	12.72	（1.5~3.0 kg/ha）	Chongqing	2.47
（＞6.0 kg/ha）	Shandong	10.55		Beijing	2.22
	Jiangsu	9.43		Jilin	2.01
	Hubei	7.29		Heilonjiang	1.80
	Hainan	7.12	Ⅳ	Shanxi	1.49
	Anhui	7.10	（0.75~1.5 kg/ha）	Sichuan	1.24
	Henan	7.07		Yunnan	0.89
	Zhejiang	6.38		Gansu	0.78
Ⅱ	Guangdong	5.52	Ⅴ	Guizhou	0.61
(3.0~6.0 kg/ha)	Jiangxi	5.32	（＜0.75 kg/ha)	Shannxi	0.52
	Hunan	5.15		Ninxia	0.34
	Fujian	4.69		Xinjiang	0.26
	Hebei	4.40		Inner Mongolia	0.15
	Liaoning	3.45		Qinghai	0.03
	Tianjing	3.12		Tibet	0.01
Ⅲ	Guangxi	2.54			

Pesticides can not only cause death but also induce various diseases. It is estimated that cancer patients resulted from pesticide poisoning account for nearly 10% of the total cancer patients (Gu and Tian, 2005). Chen (2004) found that the incidence of breast cancer was linearly correlated with the frequency of pesticide uses, and organochlorined pesticide, DDT, and its derivative, DDE, is likely responsible for breast cancer.

Table 10 Environmental persistency of some organochlorined pesticides

Pesticide	Required time for 5% residual (years)	Mean (years)
DDT	4～30	10
Dieldrin	5～25	8
Lindane	3～10	6.5
Chlordane	3～5	4
Telodrin	2～7	4
Heptachlor	3～5	3.5
Aldrin	1～6	3

Data from Tang and Li (1998)

In general, detailed data are still lacking on the impact of pesticides on human health and the environment (Pimentel, 2009a). We thereafter discuss the situation of pesticide pollution and impact in China. Organochlorined pesticides (OCPs) are parts of persistent organic pollutants (POPs), which include HCH, DDT, aldrin, dieldrin, endrin, chlordane, heptachlor, toxaphene, HCB, etc. POPs are much different from other pesticides in these aspects: they are environmentally persistent (Table 10), semi-volatile, high-bioaccumulative and high toxic (Yu et al., 2005). According to the “Stockholm Convention on Persistent Organic Pollutants”, nine in twelve POPs are organochlorined pesticides. For this reason we will mainly focus on OCPs and POPs in the following discussion.

3.1 Pesticide pollution in the environment

3.1.1 Soil pollution

According to the residual surveys of OCPs in China (Table 11), OCPs were detected in various soil types, including cultivated fields, vegetable fields, forest lands, etc. Since the use of OCPs has been banned in 1983, the residual OCPs have been declining but in some regions they are still abundant (Wang et al., 2008a).

Table 11 Residual levels of OCPs in the soils of China

Region	Monitoring year	Soil type	OCPs	HCH （$\mu g \cdot kg^{-1}$）	DDT （$\mu g \cdot kg^{-1}$）	Source
Urumuqi	2004	Cultivated fields	DDT, HCH	0.194～6.947 （Mean: 4.395）	0.52～10.438 （Mean: 3.416）	Lui et al., 2006
Yingchuan	2007	Various types	DDT, HCH, HCB, etc.	0.306～74.219 （Mean: 0.852）	0.284 ～ 1068.428（Mean: 2.236）	Wang et al., 2008a
Mianyang, Chengdu	2006	Forest lands、Cultivated fields	DDT, HCH	0.01～0.60	0.01～7.10	Li et al., 2008
Weishanhu Lake	2007	Various types	DDT, HCH	0.46～4.83	0.20～3.06	Ding, 2008

Xixi Wetland	2007	Wetlands	DDT, HCH	14.56～29.43 （Mean: 18.44）	12.82～47.36 （Mean: 20.80）	Shao et al., 2008
Northwest Sichuan to Chongqing	2006	Various types	DDT, HCH	0.06～2.10 （Mean: 0.66）	0.12～27.04 （Mean: 4.87）	Wang et al., 2008b
Beijing	2004	Various types	DDT, HCB, chlordane, aldrin, etc.		0～1830 （Mean: 76.8）	Shi et al., 2007
Central Jilin	2007	Various types	DDT, HCH, and their metabolites	0.47～13.47 （Mean: 2.00）	0.02～69.35 （Mean: 3.01）	Yu et al., 2007
Haihe River, estuary region	2007	Various types	DDT, HCH	nd～1728 （Mean: 93.9）	nd～288 （Mean: 34.4 ）	Zhao et al., 2009
Tangshan	2008	Various types	DDT, HCH	2.73～32.2 （Mean: 5.015）	11.09～141.07 （Mean: 66.4）	Liao et al., 2008
Nanjing	2002 ～ 2003	Croplands	DDT, HCH, and their metabolites	2.7～130.6 （Mean: 13.6）	6.3～1050.7 （Mean: 64.1）	An et al., 2005
Nanjing	2002 ～ 2003	Industrial lands	DDT, HCH, and their metabolites	13.8～26.1 （Mean: 19.8）	11.2～61.7 （Mean: 31.3）	An et al., 2005
Northeast Hunan	2006	Rice fields	DDT, HCH, chlordane, aldrin, etc.	1.7～25.3 （Mean: 18.2）	10.5～40.4 （Mean: 23.8）	Zhang et al., 2008a
Northeast Hunan	2006	Vegetable fields	DDT, HCH, Chlordane, aldrin, etc.	0.15～16.8 （Mean: 7.39）	6.05～57.91 （Mean: 37.77）	Zhang et al., 2008b
Xiangjiang River Valley	2004	Various types	DDT, HCB, chlordane, aldrin, etc.		0.33～3244 （ Mean: 132.31）	Chen et al., 2008a
Guangdong	2002 ～ 2005	Agri. soils	DDT, HCH, chlordane, aldrin, etc.	nd～104.38 （Mean: 5.90）	nd～157.75 （Mean: 10.18）	Yang et al., 2007
Pearl River Delta	2008	Various types	DDT, HCH	0.19～42.3 （Mean: 4.42）	3.58～831 （Mean: 82.1）	Ma and Ran., 2009
Leizhou Peninsula	2004	Various types	DDT, HCH, chlordane, aldrin, etc.	nd～65.93 （Mean: 3.43）	0.04～52.0 （Mean: 3.83）	Guan et al., 2006
Kunming	2002 ～ 2003	Various types	DDT, HCH, methamido phos,	0.08～2.33 （Mean: 1.05）	nd～153.00 （Mean: 20.89）	Chen et al., 2004

		dimethoate, etc.	

nd: not found.

3.1.2 Water pollution

Generally water bodies of croplands are mostly often polluted. The pesticide concentration of water bodies can reach the magnitude of dozens of milligrams per liter. The levels of water pesticide pollution can be ranked as: cropland water>field ditch water> runoff>pond water>groundwater> river water> deep groundwater>sea water (Lin et al., 2000).

Residuals of OCPs in some water bodies of China are indicated in Table 12. It showed that DDT, HCH, dieldrin, endrin, etc., were detected in most of the water bodies of China. The concentration of OCPs varies seasonally.

Table 12 Residual levels of OCPs in the water bodies of China

Water body	Monitoring year	Water	OCPs	∑HCH （ng/liter）	∑DDT （ng/liter）	Source
Diaocha Lake （Dry season）	2006	Surface water	20 kinds of OCPs，including DDT, HCH, dieldrin, endrin	2.27～7.72 （Mean: 5.23）	1.26～40.88 （Mean: 18.82）	Wang et al., 2007
Diaocha Lake （Wet season）	2006	Surface water	20 kinds of OCPs，including DDT, HCH、dieldrin, endrin	2.67～24.61 （Mean: 3.56）	0.61～43.24 （Mean: 11.90）	Wang et al., 2007
Guanting Reservoir	2008	Surface water	18 kinds of OCPs，including DDT, HCH, dieldrin, endrin	3.93～38.94 （Mean: 3.23）	3.71～16.03 （Mean: 8.82）	Wan et al., 2009
Suburb of Beijing	2006	Surface water	HCH, DDT	3.87～146.62	nd～13.98	Chen et al., 2008b
Middle-Down Stream, Yellow River	2006	Surface water	DDT, HCH, HCB	0.73～48.09	0.06～10.04	Sun et al., 2009
Pearl River Delta	2006	Shallow ground water	DDT, HCH, HCB, heptachlor	nd～8.00	nd～3.41	Guo et al., 2006
Port Dongzhai, Hainan （Dry season）	2006	Surface water	17 kinds of OCPs，including DDT, HCH, dieldrin, endrin	2.66～8.20 （Mean: 5.28）	5.91～54.59 （Mean: 10.28）	Liu et al., 2007

Port Dongzhai, Hainan (Wet season)	2005	Surface water	18 kinds of OCPs, including DDT, HCH, dieldrin, endrin	0.54～2.24 (Mean: 0.28)	0.28～14.0 (Mean: 6.52)	Liu et al., 2007
Estuary of Pearl River (Dry season)	2001	Surface water	DDT, HCH, dieldrin, endrin, etc.	13.8～99.7	5.85～9.53	Yang et al., 2005
Estuary of Pearl River (Wet season)	2001	Surface water	DDT, HCH, dieldrin, endrin	5.8～20.6	0.52～1.13	Yang et al., 2005

nd: not found.

3.1.3 Atmospheric pollution

Pesticides in the atmosphere are mainly from the emissions of pesticide plants, evaporation of pesticide residuals in soils and water bodies, and volatilization of pesticides sprayed, etc. Generally atmospheric pollution of pesticides is widespread. Organochlorined pesticides were detected even in the snow on Nanjiabawa Peak in Tibet, with an elevation of 4,250 m (Shan, 1997)

As can be seen from Table 13, major OCPs have been detected in the atmosphere of various regions. Atmospheric concentration of OCPs varied seasonally.

3.2 Crop and crop product pollution

Crop pollution refers to the crop phytotoxicity resulted from pesticide applications. Crop pollution is caused by pesticide spraying, seed dressing and soaking and soil treatment with pesticides. Crop pollution would affect crop growth, reduce the yield and quality of crop products. Crop pollution occurs frequently in China, as indicated in Table 14.

Table 13 Atmospheric residuals of OCPs in China

Region	Type	Monitoring year	OCPs	∑DDT (ng/m^3)	Source
Daxing District, Beijing	Gas	2005	DDT, dieldrin, endrin	0.00900 (Spring) 0.00497 (Autumn)	Shao et al., 2007
Central town, Tianjing	TSP	2002	DDT, HCH	1.874 (Summer)	Wu et al., 2003
Anhui		2005	DDT, dieldrin, endrin, etc.	0.318	Shao et al., 2007
Jiangsu		2005	DDT, dieldrin, endrin, etc.	0.772	Shao et al., 2007
Hunan		2005	DDT, dieldrin, endrin, etc.	1.11	Shao et al., 2007
Hubei		2005	DDT, dieldrin, endrin, etc.	0.336	Shao et al., 2007
Estuary of Pearl River and coastal waters of Northern	Total	2003	DDT, HCH, chlordane, etc.	0.073～0.390	Liu et al., 2008a

South China Sea					
Central town, Beijing	TSP	2002	DDT, HCH	0.962（Summer）	Wu et al., 2003
Tongzhou District, Beijing	Gas	2005	DDT, dieldrin, endrin, etc.	0.0111（Spring） 0.152（Autumn）	Shao et al., 2007

Table 14 Pesticide pollution to crops and crop products in China

Region	Year	Crop	Area	Crop or Economic Loss	Source
Shannxi	2004	Vegetables	0.0045 million hectares	Yield loss: 7.1%	Zhang, 2007
Mudanjiang	2004～2006	Soybean, maize, rice, etc.	0.1223 million hectares	Economic loss: 11.031 million RMB Yuan	Sun et al., 2007
Zhonning, Ningxia	2005～2006	Wolfberry	195 hectares	Economic loss: 5.84 million RMB Yuan	Meng et al., 2007
Jiangsu	2000～2005	Rice, wheat, cotton, etc.	0.1285 million hectares	Yield loss: 0.04687 million tons; economic loss: 0.1063 billion RMB Yuan	JSPPS, 2006
Anhui	2000～2005	20 kinds of crops, including Rice, cotton, soybean, etc.	0.0586 million hectares	Economic loss: 0.223 billion RMB Yuan	Wang et al., 2005
Boxing, Shandong	2004	Cotton	1,000 hectares		Li et al., 2005

Pesticide residuals of crop products are serious in China as well (Table 15). Pesticide residuals have been detected in grains, rapes, vegetables, fruits, tea and medicinal herbs. A survey on vegetable and fruit markets of China indicated that 41 in 81 vegetable samples were found to have pesticide residuals, of which pesticide residuals in leek and cabbage exceeded 80% and 60% of the national standard.

Table 15 Pesticide residual situation in China's markets

	Beijing		Shanghai		Guangzhou		
Sampling markets	Wal-Mart	Lotus Agriculture	AIB	Trading Market of Crop Products	Vanguard	Trading Market of Crop Products	Total
No. Samples	15	5	5	5	10	5	45
No. samples with pesticide residuals (percent)	15（100%）	5（100%）	3（60%）	4（80%）	10（100%）	3（60%）	40（89%）

No. samples with more than three kinds of pesticide residuals	13	5	3	2	9	2	34
No. samples with more than five kinds of pesticide residuals	7	3	3	2	8	2	25
No. samples with more than ten kinds of pesticide residuals	2	1	0	0	2	0	5
No. samples containing illegal or high toxic pesticides	1	2	1	1	2	2	9

Data from Green Peace (http://www.greenpeace.org/china/zh/)

3.3 Impact of pesticides on human health

The impact of pesticides on human health is divided into two categories, the chronic and the acute. Pesticide poisonings are also divided into productive poisonings, generated in the process of agricultural production, and living poisonings, i.e., suicide, ingestion, and food intake with high-residuals, etc (Liu et al., 2008b).

In China young adults from the ages 15 to 59 accounted for 84.11% of the total (Table 16). Most of human pesticide poisonings were living poisonings, of which females accounted for the most proportion. Males made up the most of productive poisonings (Table 16). Pesticide poisonings occurred mostly in the grain- and cotton-producing areas, especially cotton-producing areas. Human pesticide poisonings were mainly from Shandong, Jiangsu, Zhejiang and Hubei, totally accounted for 66% of the nation’s total.

As can be seen from Table 17, the major pesticides for human poisonings were high-toxic organophosphorus pesticides, which accounted for 86.02% of the total cases and living poisonings made up 97.92%.

Table 16 Age distribution and causes of human pesticide poisonings during 1997 and 2003

	Total			Productive poisonings			Living poisonings		
Age	Cases	Deaths	%	Cases	Deaths	%	Cases	Deaths	%
0～	6291	244	3.88	251	1	0.40	6040	243	4.02
15～	47447	2641	5.57	9669	77	0.80	37778	2564	6.79
35～	43710	2823	6.46	15241	84	0.55	28469	2739	9.62
60～	3951	435	11.01	1236	13	1.05	2715	422	15.54
65～	2633	390	14.81	627	10	1.59	2006	380	18.94
70～	4322	903	20.89	482	14	2.90	3840	889	23.15
Unknown	18	1	5.56	5	0	0.00	13	1	7.69
Total	108372	7437	6.86	27511	199	0.72	80861	7238	8.95

Table 17 Distribution of pesticides and pesticide poisonings

Category	Cases	%	Deaths	%
Insecticides	92144	86.02	6596	7.16
Organophosphorus	79295	86.06	5945	7.50
Methamidophos	27335	34.47	2327	8.51
Parathion	11798	14.88	671	5.69
Omethoate	9683	12.21	1128	11.65
Dichlorvos	9451	11.92	734	7.77
Others	21028	26.52	1085	5.16
Pyrethroids	2954	3.21	61	2.06
Carbamated pesticides	3225	3.50	246	7.63
Other insecticides	6670	7.24	344	5.16
Rodenticide	5284	4.88	342	6.47
Other pesticides	8397	7.75	428	5.10
Herbicides	2163	25.76	74	3.42
Pesticide mixtures	2524	2.33	68	2.69
Unknown	23	0.02	3	17.39

Data from Chen et al. (2005).

4 Future Trend of Pesticide Production and Consumption

Pesticides in the future should possess the following characteristics: first, they should be highly efficient, which requires a high biological activity and thus may greatly reduce pesticide uses and minimize pesticide pollution of the environment; second, they should be non-toxic; third, they are pollution-free, that is, they are environment-friendly pesticides.

Biopesticides are living organisms, their metabolites in vivo, and genetically modified products that are commercially manufactured to control diseases, insect pests, weeds and other harmful biological organisms (Zhang and Zhang, 1998). They include microbial sourced (bacteria, viruses, fungi and their secondary metabolites like agricultural antibiotics), plant sourced and animal sourced products, and pest-resistance transgenic plants (Zhu et al., 2002; Zhang and Pang, 2009). Biopesticides possess the following advantages: (1) good control effect on the pests, safe to humans and animals, no pollution, and no residuals; (2) strong specificity to target pests, safe to natural enemies and beneficial organisms; (3) raw materials and active ingredients are natural products which helps to ensure sustainable development; (4) they can be modified by means of modern biotechnology and fermentation process to improve performance and enhance quality; (5) pest resistance is difficult to generate (Yang, 2001).

Currently there are more than 100 kinds of biopesticides in the world, of which more than 30 kinds of biopesticides are commercially manufactured (Xu, 2008). Mexico, the United States and Canada are the countries mostly using biopesticides in the world. Consumption of biopesticides in these countries accounts for 44% of the world, while biopesticides consumption of Europe, Asia, Oceania, Latin America, the Caribbean and Africa accounts for 20%, 13%, 11%, 9% and 3% of the world respectively (Qin and Kong, 2006).

In China, biopesticides industry has been developing rapidly since 1990s, with an annual rate of 10% to 20%. A variety of biopesticides have been registered (Table 18).

Table 18 Registrations of biopesticides in China in 2004

Ingredient	No. active ingredients	No. products	Detail
Bacteria	11	37	2 kinds of Bt varieties
GM bacteria	1	1	Genetic modified Bt
Fungi	6	11	4 kinds
Viruses	12	24	6 kinds of ingredients were registered in the form of mixtures
Antibiotics	29	120	9 for insect pests, 19 for bacteria, and 1 for weeding
Plant-sourced pesticides	44	108	
Biochemical pesticides	37	111	Include GA, oligosaccharides, brassinolide, Harpin and other plant growth regulators and pheromones

Data from Zheng (2006)

During 2006 the total consumption of biopesticides in China reached 145,000 tons, with a sale accounting for 10% of pesticides. In China's pesticide markets, Bt accounted for 2%, agricultural antibiotics accounted for 9% and botanical pesticides accounted for 0.5%. It is estimated that biopesticides will replace more than 20% of chemical pesticides in the future.

Despite the advantages above, biopesticides are not perfect. Their slow response to pest outbreaks, higher prices and poor stability limit their further development and application. Solutions must be found to improve their performance and reduce production cost.

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