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Mitigating Pesticide Pollution in China Requires Law Enforcement, Farmer Training, and Technological Innovation

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Abstract—*To feed an ever-growing population, it is necessary to take all measures to increase crop yields, including the use of pesticides. It has long been a difficult task to boost agricultural production and simultaneously minimize the impact of pesticide application on the environment, particularly in China, a developing country with more than 1.3 billion people. China has recently become the world's leading producer and consumer of pesticides, with production and consumption reaching 265 tons and 179 tons, respectively, in 2011, and a national average pesticide application dosage of more than 14 kg/ha. The large quantities of pesticides applied in agricultural fields have resulted in serious environmental deterioration. Organochlorine pesticides, such as dichloro-diphenyl-trichloroethane and hexachlorohexane, have become ubiquitous in the environment of China, with spatial distributions in soils and aquatic systems similar to their historic application patterns in different geographic regions: southeast > central > northwest. Pollution by current-use pesticides, for example, organophosphates and pyrethroids, has also been of great concern. To mitigate pesticide pollution in China, a significant reduction in pesticide inputs into the environment is mandatory. This can be accomplished only with joint efforts by the government, professionals, and citizens in combination with rigorous enforcement of laws and regulations, training of farmers in pesticide knowledge and environmental awareness, and technological innovation for producing low-risk pesticides and developing efficient application approaches. Restoring contaminated sites is also an urgent task. Finally, food security and environmental pollution are not problems for a sole country, and international cooperation and communication are necessary.* Environ Toxicol Chem 2014;33:963–971. © 2014 SETAC

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Introduction

A *pesticide* is a substance or a mixture of substances designed for repelling, controlling, or killing pests, such as insects, weeds, mites, and rats. Pesticides often include insecticides, herbicides, fungicides, acaricides, rodenticides, and other substances used to control different target pests. Unlike most environmental stressors, pesticides are manufactured to have biological activity and to be released into the environment intentionally in large quantities. The use of pesticides is vital to increasing agricultural yields to feed growing populations, but the threat of pesticides to the environment and public health are of great concern. Therefore, it has long been a challenge to balance the benefit and the risk of pesticide application; and apparently, the magnitude of the challenge is proportional to the size of the population.

Pesticide Production and Consumption in China

China is the world's most populous nation, home to more than 1.3 billion residents; but the per capita farmland area is less than 0.1 ha/person, which is approximately 40% of the world's average and one-fifth of that in the United States [1]. Ensuring food security for such a population is, should be, and will continue to be a top priority for the government and the scientific community.

China is also one of the most rapidly developing countries, and it is currently in the transition from a rural to an urban society [2]. Serious environmental pollution and shortage of water resources, largely the result of rapid economic development, along with losses of farmland and the agricultural labor force, as a result of expanding urbanization, have aggravated the food problem in this country. In view of the ever-growing population and limited food sources, it is crucial to take all measures to substantially boost crop yields, such as the extensive use of fertilizers and pesticides [1]. The benefits of pesticide application are evident; for example, the use of pesticides in China avoided losses of 70.5 million tons of cereals, 2.53 million tons of oilseeds, and 2.01 million tons of cotton in 2007 [3].

China's pesticide industry was initiated in the early 1980s and has experienced rapid development during the last 30 yr. The nationwide pesticide production and consumption data from 1983 to 2011 in China are presented in Figure 1 [4]. In the early years, pesticide consumption in China relied mainly on imports because domestic production capacity was low. Pesticide production has risen sharply since then and exceeded 1 million tons in 2005. In 2007, China became the world's largest pesticide producer. More than 2.6 million tons of pesticides were produced in China in 2011, with an export volume of 0.79 million tons [4].

The use of pesticides in China also has increased sharply, from 0.76 million tons in 1991 to 1.8 million tons in 2011, amounting to an average annual growth rate of 4.9% [4]. The growth will continue, and the demand for formulated pesticides is forecast to approach 2.3 million tons in 2015 [5]. The growth of pesticide consumption is driven primarily by more intensive agriculture to meet the growing demand for food. As reported by Zhang et al. [1], 30% to 50% more food will be needed in China in the next 2 decades, suggesting an even stronger demand for pesticides in the future. Moreover, the change in crop composition also stimulates a gradual increase in pesticide demand. Relative to other crops, fruits and vegetables are more vulnerable to pest damage and require more frequent pesticide application. Therefore, the ongoing expansion in the production of fruits and vegetables, particularly in metropolitan peripheral areas, has enhanced the use of pesticides. Finally, the rising demand of pesticides is also related to economic growth, climate change, and pesticide resistance.

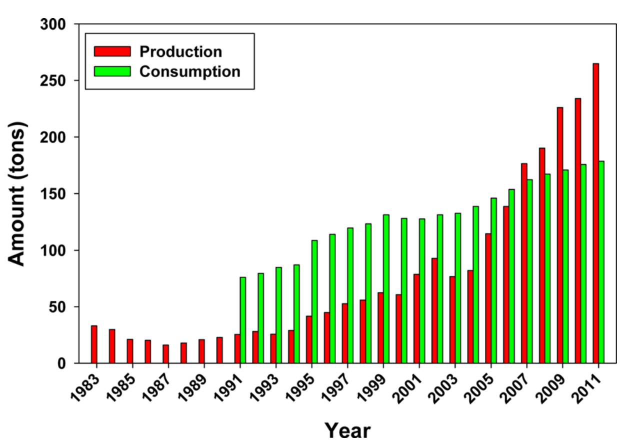


FIGURE 1: Nationwide pesticide production and consumption in mainland China from 1983 to 2011. The graph was constructed using data from the 2012 China Agricultural Development Report [4].

From a geographic perspective, it is interesting to note that pesticide consumption is linked to local economic and climatic patterns. Figure 2 depicts the relationships between pesticide application in the 31 provinces of mainland China and gross domestic product as well as the annual average temperatures of the provincial capital cities [6]. The total usage of pesticides in a province is directly related to the gross domestic product (Figure 2a). The provinces with intensive pesticide application are generally located in central and eastern China, which are also more economically developed than the western region. Favorable economic conditions increase farmers' willingness

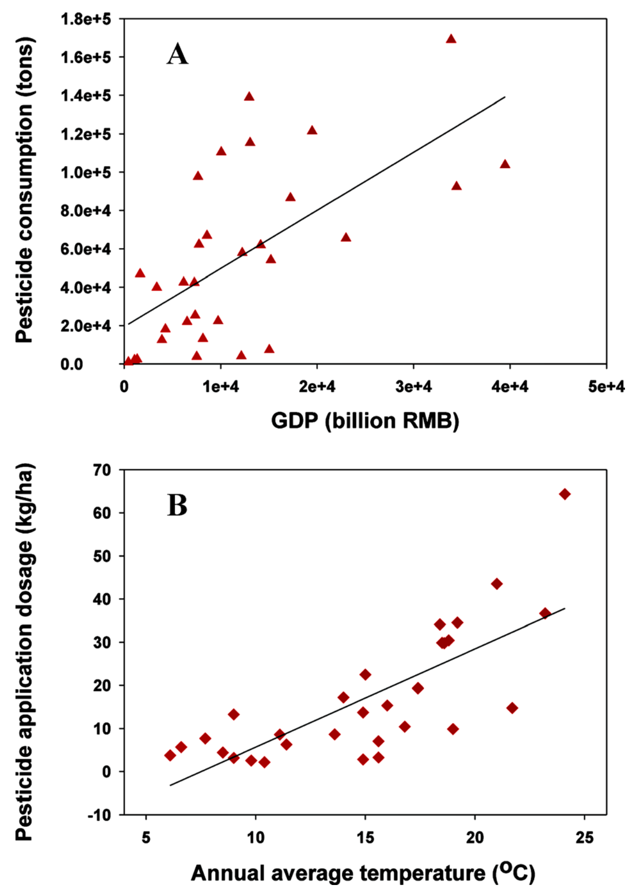


FIGURE 2: The impacts of local economy and climatic pattern on pesticide consumption in mainland China. (A) The relationship between the total pesticide consumption in a province (tons) and the gross domestic product (GDP; billion renmingbi [RMB]) (pesticide consumption $= [3.0 \times \text{GDP}] + [1.9 \times 10^4]$; $r^2 = 0.42$, $p < 0.001$). (B) The relationship between pesticide application dosage (kg/ha) and the annual average temperature of provincial capital cities (pesticide application dosage $= [2.28 \times \text{annual average temperature}] - 17.2$, $r^2 = 0.58$, $p < 0.001$). All data are from 2009, pesticide consumption data are from *China Rural Statistical Yearbook 2010* [6], and gross domestic product and temperature data are from the websites of the National Bureau of Statistics of China [24] and the China Meteorological Administration [25], respectively.

to use pesticides for bolstering crop yields, creating the scenario that richer farmers tend to use more pesticides. Furthermore, it is not surprising to see that weather conditions play a role in pesticide application (Figure 2b). Pest outbreaks and plant diseases occur more frequently under warm and humid weather conditions in southern China than in other parts of China, promoting the use of pesticides. In addition, high temperatures and frequent rainfalls in southern China may increase the loss of pesticides through evaporation and runoff, which can reduce their efficacy. As a result, global warming is expected to lead to the use of more pesticides in the future.

Specifically, 9 provinces (Anhui, Guangdong, Henan, Hubei, Hunan, Jiangsu, Jiangxi, Hebei, and Shandong), each consumed more than 85 000 tons of pesticides in 2009, which collectively accounted for 61.7% of the nationwide consumption of pesticides [6]. Conversely, 7 provinces in northwest China (Gansu, Inner Mongolia, Ningxia, Qinghai, Shannxi, Tibet, and Xingjiang) only used 5.4% of the national total [6].

Pesticide application dosage is defined as the pesticide consumption per area of cultivated land in a province [6]. The distribution pattern of the pesticide application dosage in China is clearly characterized by southeast > central > northwest (Figure 3). Hainan Province had the highest pesticide application dosage (64.3 kg/ha), followed by Fujian (43.5 kg/ha) and Guangdong (36.6 kg/ha), whereas Ningxia had the lowest pesticide application dosage (2.2 kg/ha) (Figure 3). All 14 provinces that had pesticide application dosage values higher than the national average (14.0 kg/ha) are located in the eastern and central regions of China.

Herbicides have dominated the pesticide market in developed countries; for example, more than 60% of pesticides consumed in the United States are herbicides. Insecticides, however, are the leading pesticides in China, accounting for 78% of pesticide consumption in the 1990s [7]. In recent years, the proportion of insecticides in pesticide products has significantly declined in China, yet it remained the highest (~40%), followed by herbicides (31%), fungicides (25%), acaricides (3%), and plant growth regulators (1%) in 2012 [8]. In addition, insecticides normally pose greater adverse effects on human beings than other classes of pesticides; thus, the present discussion on pesticide pollution will focus mainly on insecticides.

Pesticide Pollution in China

Pesticide production and consumption in China have soared in the past 30 yr, and large quantities of pesticides have been applied in both rural and urban areas. By the end of 2009, more than 26 000 pesticides had been registered in China, and almost half of them were insecticides. Though the number seems huge, most insecticides belong to several classes with similar chemical structures and modes of action. The demand for each class of insecticides in China from 2006 to 2013 is shown in Table 1.

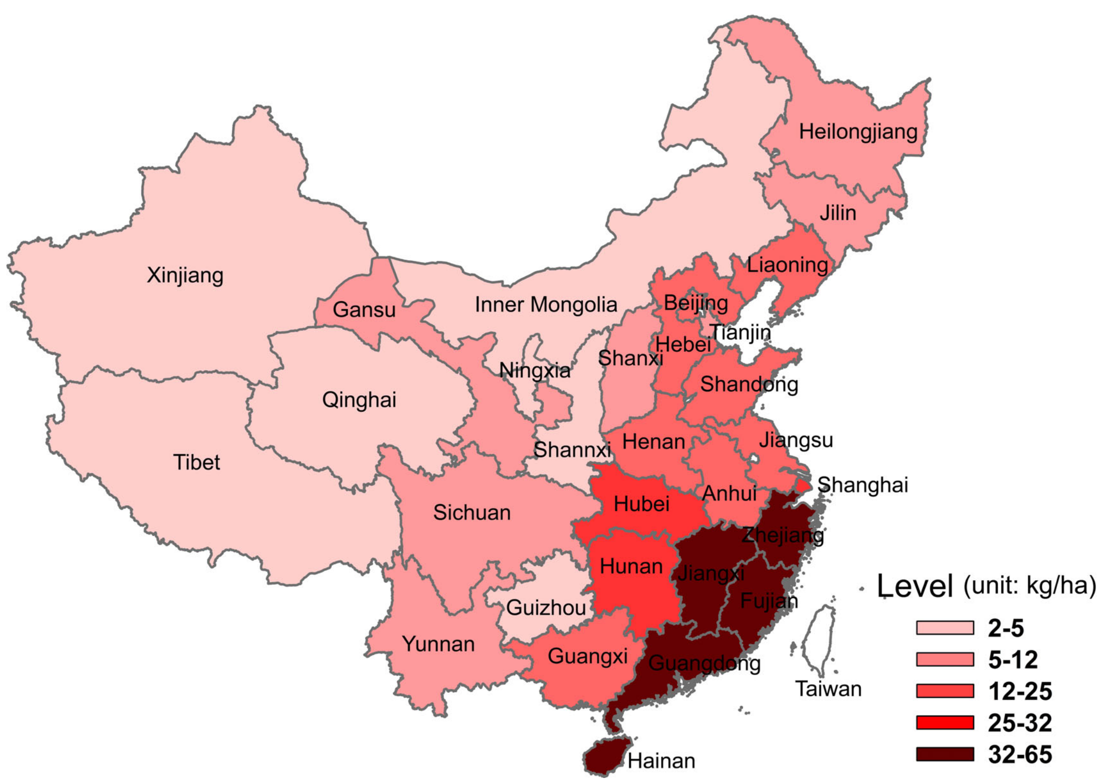


FIGURE 3: The distribution pattern of pesticide application dosage in mainland China in 2009. The graph was constructed using data collected from *China Rural Statistical Yearbook 2010* [6].

Table 1. The demand for each class of insecticides in mainland China from 2006 to 2013[a]

Year	Organophosphates	Carbamates	Pyrethroids	Others
Demand for insecticides (tons)				
2006	93 700	5271	8777	34 800
2007	94 300	6714	3875	31 100
2008	88 300	7567	3882	29 800
2009	95 900	10 200	4472	31 600
2010	93 300	7135	3624	25 400
2012	91 100	5800	3700	23 600
2013	86 300	5800	3600	25 100
Percentage of the total				
2006	66%	3.7%	6.2%	24%
2007	65%	4.6%	2.7%	21%
2008	63%	5.4%	2.8%	21%
2009	63%	6.7%	2.9%	21%
2010	72%	5.5%	2.8%	20%
2012	73%	4.7%	3.0%	19%
2013	71%	4.8%	3.0%	21%

[a]All data were collected from the following websites: http://www.sdpc.gov.cn/xxfw/hyyw/t20051205_52488.htm; http://wuxizazhi.cnki.net/Article/NCSY200701006.html; http://www.ahnw.gov.cn/2006schq/html/200712/%7BD85D937F-7FFB-460C-B061-A3DC239CEC00%7D.shtml; http://www.gov.cn/gzdt/2008-10/24/content_1130111.htm; http://www.chinapesticide.gov.cn/doc09/09112306.html; http://www.chinairn.com/news/20120208/925304.html; http://www.chinapesticide.gov.cn/doc12/12121727.html.

The history of insecticide use in China is not different from that in the rest of the world. Since their production in the 1950s, organochlorine insecticides such as DDT and hexachlorocyclohexane (HCH) had been heavily used in China. Because of the increasing awareness of their high persistence and bioaccumulation potential, the use of these 2 organochlorine insecticides was banned in China in 1983. Since then, organophosphate insecticides have dominated China's insecticide market, accounting for approximately 70% of the insecticide demand. Carbamates, which target the same site of acetylcholinesterase as the organophosphate insecticides, have also been widely used. Owing to their high mammalian toxicity, some organophosphate insecticides and carbamates have been linked to direct poisoning events. In 2007, 5 highly toxic organophosphate insecticides (methamidophos, parathion-methyl, parathion, monocrotophos, and phosphamidon) were phased out in China. A shift to insecticides with less mammalian toxicity—for example, pyrethroids and biopesticides—is occurring, although the change has been gradual.

Compared with the shifting pattern in pesticide application, research on pesticide pollution in China has lagged far behind. Most studies to date have focused on the environmental occurrence, distribution, source, and risk of legacy organochlorine insecticides in the southern and eastern regions of China. Particularly, environmental pollution and management of DDT and HCH are the popular topics and have been well reviewed at both regional [9] and national [7,10,11] scales. On the contrary, studies on the environmental occurrence and ecotoxicological risk of current-use pesticides are scarce in China [12].

Because of their large-scale use in agriculture in the past, DDT and HCH have become ubiquitous in the environment and frequently detected in soil, water, sediment, air, and biota in China [7,9,10]. The spatial distribution of organochlorine insecticide residues is similar to the pesticide consumption pattern, southeast > central > northwest [7]. Moreover, organochlorine insecticide residues are normally more abundant in vegetable fields than in other crop fields [7]. This is because pesticide spraying is generally more frequent on vegetables and fruits than on other crops. Although levels of DDT and HCH have gradually declined since the official ban on their use, their environmental concentrations in China are still higher than those in developed countries [7,9]. Concentrations of DDT and its metabolites in the environment of the Pearl River Delta, South China, where vast amounts of organochlorine insecticides had been applied for a long time, are at the high end of the global range [9]. Currently, *p*,*p*-DDT in the Pearl River Delta is largely distributed in soil (780 tons) and its concentration is expected to decrease to half of the present level after 22 yr [13]. Conversely, DDT concentrations have hardly changed since 1983 in some locations, suggesting the presence of new input sources, such as DDT residues in dicofol and DDT-containing antifouling paints for boat maintenance, as contributors of new DDT compounds [14,15].

Fewer studies have been conducted on other organochlorine insecticides and current-use pesticides compared with DDT and HCH [12,16–18]. Although the environmental occurrence of current-use pesticides has only been sparsely investigated in China, their adverse impacts on society have been noted; for instance, poisoning events associated with organophosphate insecticides and carbamates are frequently headline news. In addition to the extreme cases of acute toxicity induced by highly toxic current-use pesticides, exposure to the so-called low-risk current-use pesticides has also been linked to chronic health effects recently, such as pyrethroid-related impairment of sperm DNA integrity and organophosphate insecticide–related change in duration of gestation [19,20]. Wang et al. [20] found that levels of organophosphate insecticide metabolites in urine samples from Shanghai, eastern China, were higher than those in developed countries, indicating greater organophosphate insecticide exposure. Because of the requirements of food safety regulations [11], increased monitoring studies have been performed on current-use pesticide residues in food from Chinese markets [21]. Nevertheless, the occurrence of current-use pesticides in the environment and the impacts of current-use pesticides on ecosystems have remained rarely studied.

The continual input of current-use pesticides into the environment makes them pseudopersistent stressors, although they are less persistent than legacy organochlorine insecticides. Consequently, abundant current-use pesticides have been detected in aquatic systems of China [12,17,22]. A survey of organophosphate insecticides in surface water at the national scale suggested that Chinese rivers have been contaminated by dichlovos and demeton [22]. Concentrations of organophosphate insecticides in water were greater in northern China than in southern China [22], which is contrary to the spatial distribution of their application: south > north. This finding is difficult to comprehend, but rapid degradation of organophosphate insecticides at high temperatures and dilution effects as a result of more rainfalls in South China may be plausible explanations.

Because they are more hydrophobic, pyrethroids have been detected in sediment in the Pearl River Delta with higher frequencies and greater abundances than organophosphate insecticides. Cypermethrin, a pyrethroid, was identified as one of the major toxicity contributors to benthic invertebrates in this area [12]. Analysis of sediment-associated current-use pesticides in a lake receiving waters from areas undergoing rapid urbanization suggested that organophosphate insecticide residues were mainly from agricultural non–point sources, whereas pyrethroids were from urban runoff [17], such as application in mosquito control, landscaping maintenance, and structural maintenance. This shows that pesticide consumption in urban areas may be an important source of pesticide pollution, especially in rapidly urbanizing regions [2].

The occurrence and distribution of pesticides, on entering the environment, are affected by a variety of factors, such as physiochemical properties, application history, agricultural practice, and local environmental settings and meteorological conditions. In addition to being detected in aquatic systems, current-use pesticides were detected in the atmosphere of southern China [18]. The detection of these chemicals in different environmental compartments points to the need to better understand their environmental fate. The disparity of atmospheric depositional fluxes in the Pearl River Delta among DDT, chloropyrifos, and cypermethrin may be explained by the difference in their physiochemical properties and application histories (Case 1, Zhang et al. [13], and H. Li, unpublished data).

To date, most studies on pesticide pollution in China have been conducted in the southern and eastern regions, which are more economically developed. The distribution patterns of pesticide application in 1996 [7] and 2009 (Figure 3) were quite similar, although the national average pesticide consumption had increased from 2.71 kg/ha to 14.0 kg/ha. Interestingly, the growth in pesticide consumption in 4 provinces of north China (Gansu, Heilongjiang, Jilin, and Shanxi) outpaced that in other regions during this time period. Relative to central and eastern China, the northern and western regions have more potentially available farmlands; and recent economic growth benefiting from the Great Western Development Strategy and the Northeast Development Plan may enhance pesticide use in these regions. Hence, more efforts should be directed toward pesticide pollution research in the northern and western regions, although substantially lower amounts of pesticides have been used in these areas compared with the central and eastern regions.

Perspectives on Pesticide Mitigation in China

It is evident that the growing use of pesticides has posed significant threats to the environment; however, we have no choice but to continue to use pesticides. Instead, our goal is to gain the benefit of boosting crop yields but to minimize damage to the environment. The challenge is gigantic, but the effort of balancing the benefits and risks of pesticide application is valuable. When the mission is accomplished, it will not only alleviate the environmental problems in China but also provide an example for sustainable agriculture in developing countries.

To mitigate the environmental impacts from pesticide consumption, the key is to reduce the inputs of pesticides to the environment. As discussed in the section *Pesticide Production and Consumption in China*, pesticide application dosage in China, particularly in its southern and eastern regions, is incredibly high and continues to increase. Overuse of pesticides is the result of low efficacy of pesticide application and increased pesticide resistance, which may be related to improper use of pesticides, such as long-term usage of a single pesticide. In addition, ineffective pesticide management and outdated pesticide spraying techniques may have inflated the problem. Thus, to mitigate pesticide pollution in China, it is necessary to strengthen the enforcement of laws and regulations for production and use of pesticides, improve application efficacy by educating the end users (farmers), and innovate the spraying techniques.

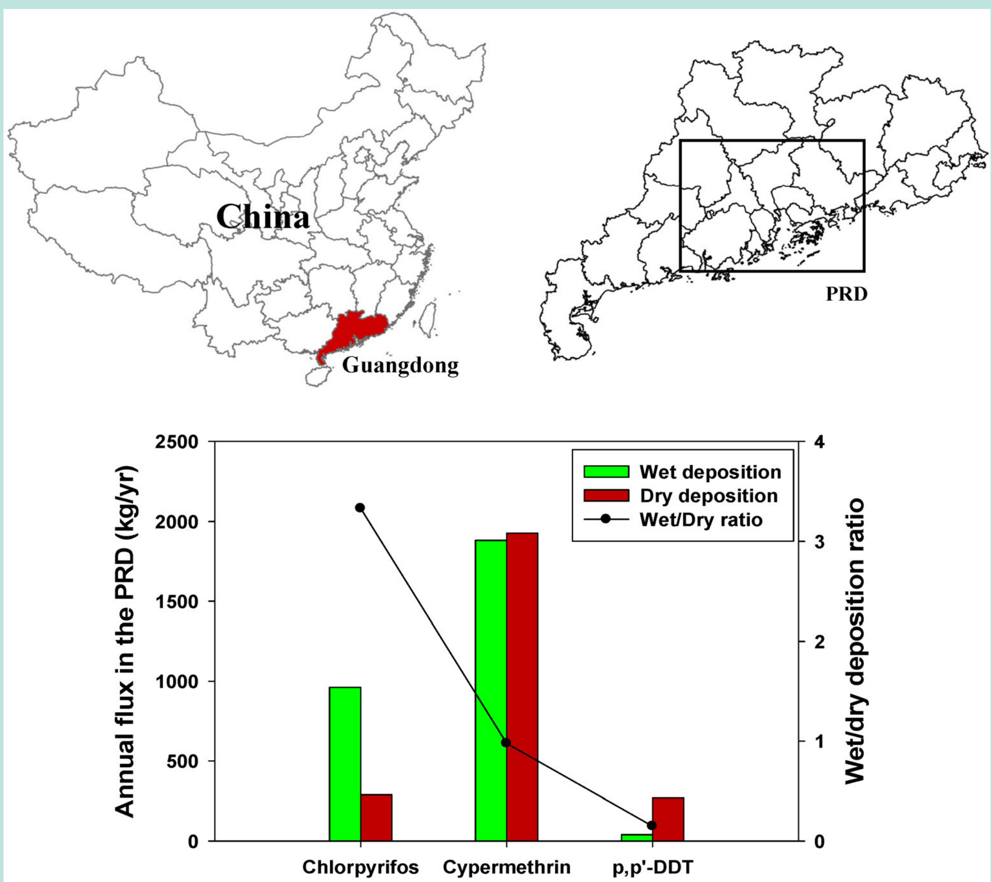
First, we need not only laws on paper but also rigorous enforcement of these laws in reality. In China, the legal system

Case 1: Application History and Physicochemical Property Determine the Destination of Pesticides in the Environment

The Pearl River Delta is one of the most populous and economically developed regions in China. Located in the subtropical zone of South China, the Pearl River delta benefits from mild temperature, heavy rainfall, and humid weather for agricultural practices; but these conditions also promote insect propagation. Thus, this area has a long history of insecticide use, first legacy organochlorine pesticides and then current-use organophosphates and pyrethroids. To better understand the transport and fate of pesticides in the environment, atmospheric deposition of 3 insecticides—an organochlorine (*p,p′*-DDT), an organophosphate (chlorpyrifos), and a pyrethroid (cypermethrin)—has been estimated in the Pearl River Delta in previous studies ([13]; H. Li, unpublished data). All 3 insecticides have been frequently detected in different environmental compartments in the Pearl River delta [9,12,13,18].

Probably because they are still currently used in large quantities, atmospheric depositional fluxes of chlorpyrifos (1250 kg/yr) and cypermethrin (3809 kg/yr) are much higher than that of *p,p′*-DDTs (310 kg/yr), which was banned for use in 1983 in China. Furthermore, a significant difference was noted for the wet and dry deposition ratios for the 3 insecticides: 3.3, 0.97, and 0.15 for chlorpyrifos, cypermethrin, and *p,p′*-DDT, respectively. Chlorpyrifos has a higher vapor pressure relative to cypermethrin and *p,p′*-DDT and, consequently, higher gaseous concentration and higher wet dissolved depositional flux.

All are insecticides and have been heavily used in the same area. Yet their differing application history and physicochemical property determine where they are in the environment. Research is required to understand the occurrence, transport, and risk of different types of insecticides that were used many years ago and those that are currently in use. We cannot simply assume what will happen next from past experience only.



PRD = Pearl River delta.

can be categorized as acts, regulations, ordinances, and criteria [7]. For better pesticide management, 2 ordinances (Ordinance of Pesticide Registration and Ordinance of the Safe Use of Pesticide) were issued in 1982, and then the Regulation on Pesticide Management was issued in 1997. Currently, revision of the regulation is in progress. New articles have been added, establishing licensing systems for pesticide sales, for example, and making it the responsibility of end users for recycling pesticide containers. Moreover, establishing criteria on pesticide residue limits, that is, maximum residue limits in various crops, is currently in full swing with the goal of improving the international competitiveness of agricultural products. There were 807 pesticide residue limits in 2008, and the number is expected to reach 7000 by the end of 2013.

The changes are welcome, especially if they can be fully implemented. Improper disposal of pesticide containers after use is still a common practice (Figure 4). The containers shown in Figure 4 were found in the field during our trip to a small village in southern China. Based on the licensing system for pesticide sales, records for all pesticides being sold should be maintained for at least 2 yr. This has not yet happened, at least not as of fall 2013 according to a farmer in the small village (Case 2).

Case 2 calls for enhanced implementation of the laws. The completion of the regulations and criteria is good news for pesticide management, but only effective enforcement of the laws can realize the changes put on paper. We cannot expect all law offenders to repent because of their conscience; it is the punishment that makes them realize the consequences of breaking the laws. Without law enforcement, counterfeit pesticides will still be produced, the pesticide circulation market will still be in chaos, and disposed pesticide containers will still be found in the environment.

Next, training end users of pesticides is of utmost importance. Pesticide application efficacy in China is less than 30%, and the situation will become even worse because of pesticide resistance. To alleviate pesticide pollution, we must educate farmers. The majority of Chinese farmers, as those in other developing countries, are poorly educated, thus it is difficult for farmers to properly understand and follow the instructions on the labels for pesticide spraying, not to mention that the labels are sometimes misleading. For example, hundreds of names have been used for the same pesticide on the market, and the major ingredients of a pesticide are not clearly stated on labels. Therefore, most farmers choose and use pesticides based on advice from their acquaintances or dealers. In some cases, the same pesticide is used for different insect attacks. Farmers may not understand that long-term use of a single pesticide may promote resistance, which subsequently requires more pesticide. In some cases, dealers may, for their own benefit, persuade farmers to overuse pesticides or may sell unqualified pesticides (Case 2). Furthermore, farmers may not be aware of the environmental hazards of pesticides; some farmers are even unaware of the importance of self-protection, for example, during pesticide spraying (Figure 4).

FIGURE 4: Pesticide sale and spraying. Improper disposal of pesticide containers in the enviroment and unprotected spraying are shown.

In this situation, it is urgent to develop professional teams to assist farmers. Agricultural cooperatives have demonstrated great potential for pest prevention with lower environmental damage because pesticide spraying is conducted on a large scale by specialized workers. Furthermore, information about pesticide-induced environmental hazards should be widely disseminated. Farmers need greater guidance on proper disposal of pesticides to better understand the environmental risks associated with pouring leftover pesticides on the ground, casually throwing away pesticide containers, and washing equipment for pesticide spraying in rivers or streams.

Lastly, technological innovations and improvements are crucial for further alleviating environmental pollution by pesticides. Science-based law institutions will make the laws more rational. Development of new generations of pesticides with less environmental impact and improvement of pesticide application efficacy also will benefit from technological innovation. China is moving in this direction. A large-scale project funded by the National "973" Program, namely, the Green Pesticide Research Project, was initiated in 2003 to design novel pesticides, such as biopesticides; the project is currently in its second phase (2010–2014) [23]. This type of national-level study has demonstrated the Chinese government's commitment to significant scientific innovation. Moreover, research on improving pesticide application techniques for more precise, low-volume, and targeted spraying, such as the sustained-release technique, and developing new crop varieties and hybrids will also contribute to the mitigation of pesticide pollution [1,23].

Overall, mitigation of pesticide pollution in China requires a substantial reduction of pesticide input into the environment. This can largely be done with the cooperation of the government, professionals, and citizens through completion and enforcement of laws and regulations, training farmers with pesticide knowledge and environmental awareness, and technological innovation for producing low-risk pesticides and high-efficacy application procedures. Furthermore, food security and environmental pollution are not the problems of an isolated country or region only, and international cooperation and communication are necessary.

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Case 2: Urgent Need to Conduct Farmer Training and Enforce Sale Registration

The following is a true story about improper use of pesticides in a small village in South China, where 2 seasons of rice planting is the main agricultural practice. Paddy rice is the most widely planted crop in South China and is vulnerable to various pests, such as planthoppers and stem borers. Therefore, insecticide application is common for mitigating the damage from pests, and more than 6 sprayings are generally required until the rice harvest; but what type of pesticides should be used? When is the best time to spray pesticides? Where do farmers gain knowledge of pesticides?

In this small village, farmers typically buy pesticides from private pesticide retail shops. The owners of the shops are villagers. Some of them may have a little knowledge of pesticides and some may not. They are not professionals, but they are the individuals who advise farmers about the pesticides.

We were told by a farmer that the fall 2013 rice harvest in her plot was less than 70% of previous harvests. The loss was the result of insect attacks, even though she sprayed pesticides 8 times during the entire crop growth period. Before the heading and flowering time for the rice, insects appeared. The farmer was persuaded by a shopowner to try new pesticides. After the application, she noted that the crops were still suffering from insect damage, so she went back to the same pesticide retail shop for more suggestions. This time, she was told to try old brands. She did, and nothing improved. Surprisingly, she found that the pesticide she had bought from the store was out of date. During these 2 attempts, the rice started heading, and the key time for pest control passed. As a result, she lost one-third of her crops.

Here, pesticides were used, and even used twice, but crop yields were reduced. The problem was caused by improper guidance of pesticide use and the sale of expired pesticides in the local retail store. How can such situations be avoided? It is time to conduct farmer training and to enforce sale registration.

This type of story may happen again and again in China, where small farms (<0.1 ha) are typical [1]. Farmers working with such small plots may be less inclined to take the initiative to acquire knowledge of pesticides. There is an urgent need to develop professional teams to assist farmers. Knowledge of pesticide-related environmental hazards should also be widely propagated. Furthermore, it is necessary to enforce a formal licensing system under the Regulation of Pesticide Management so that expired pesticides will no longer be sold.

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