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No. 2001-RR3

Farm Pesticides, Rice Production, and Human Health in China

Jikun Huang, Fangbin Qiao, Linxiu Zhang, and Scott Rozelle
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This report investigates the causes and effects of excessive use of pesticides in Zheijing province, China. It finds that overuse occurs primarily because farmers overestimate crop losses from pests. The most serious effects are health damages and unnecessary expenditures on pesticides. Programs to educate farmers about appropriate use are recommended.

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FARM PESTICIDES, RICE PRODUCTION, AND HUMAN HEALTH IN CHINA

Jikun Huang, Fangbin Qiao, Linxiu Zhang and Scott Rozelle[1]

1.0 INTRODUCTION

Pesticides of various kinds have been used on a large scale in China since the 1950s to protect crops from damages inflicted by insects and diseases. Annual pesticide production reached more than 500,000 metric tons after the mid-1990s (Huang et al., 2000). China was the second largest pesticide-using country in the world in the 1980s and is the largest pesticide-using country in the world in the 1990s (Wang, 1999).

Although intensive pesticide has increased grain production, its use has several drawbacks. In addition to the direct costs of the pesticides, long-term and highly concentrated application of pesticides may contaminate the products of field crops, as well as pose a serious danger to the agro-ecosystem (e.g., the surrounding soil and water quality) and human health (Rola and Pingali, 1993).

With the expansion of employment in rural enterprises (industries) and urban sector, the opportunity cost of agricultural labor has risen. The farming sector has become a part-time job in many areas of the eastern and coastal regions of China. This change is likely to have negative impacts on the environment because of the substitution of chemicals for labor (Ye, 1991; Huang and Rozelle, 1996). Labor shortages may also lead to improper application of pesticides. The deterioration of the agricultural extension system due to inadequate financial support from the government since the mid-1980s further adds to the concern for proper use of chemicals in crop production (Huang, et al., 1999a).

Given the prospects of China's food situation in the coming century and the central goal of China's food security policy (Fan and Agcaoili, 1997; Huang et al., 1999b), intensive cropping systems will likely continue to be the dominant

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farming practice in China. Most observers of Chinese agriculture believe that there will be an increasing use of farm pesticides because farmers perceive pesticides to have large impacts on crop yields. The reliance on pesticides for plant protection is expected to lead to more dependence on and to rising use of pesticides due to rapid development of resistance among China's current varieties (Widawsky et al., 1998).

This is not to say that the government has ignored the environmental and health risk connected with farm pesticide use. Effort has been made by the Chinese government to regulate production of highly toxic pesticide, promote safe use, and management of pesticides during the reform era. Before the 1980s, policies have focused on the safe handling of agricultural chemicals. In the 1980s, regulations were developed for safe use of pesticides with bans imposed on highly hazardous organochlorine (BHC and DDT), organomercurial and organoarsenical pesticides. The Government has also created standards for acceptable daily intake level and maximum allowable levels of residue on crops. However as experience has shown, the promulgation of rules and regulation did not guarantee improvements in the proper and safe use of pesticides. There is increasing concern on environmental pollution and harmful human health consequences of agricultural chemical pesticide use. The amount of farm pesticide use has increased rapidly in recent years and farmers in many areas show little knowledge of efficient and safe use of pesticides. To date, there are few studies that analyzed the negative impacts of chemical pesticide use on grain, the environment, and human health.

In seeking to have a clear understanding of the consequences of increasing farm pesticide use on agricultural production, environment and human health in China, and to identify the policies that will help farmers reduce their pesticide use yet maintain the profitability of crop production, several critical questions arise. What are the trends of production, utilization, and trade of chemical pesticides in China? How much pesticide is currently applied to crop production? How do government policies and regulations affect the production, utilization, and trade of chemical pesticides? What are the determinants of pesticide adoptions by farmers? What are the impacts of pesticide use on crop production, the environment, and farmer's health? What are the benefits and costs of farm pesticide uses in grain production? And what are the alternatives to pesticide use in crop production?

Answers to the above questions are by no means clear in China. Officials from the Ministry of Agriculture claim that increasing grain yield and production is the priority in an economy where per capita income of farmers is still low. Others believe that it is important for China to consider this as an integrated part of sustainable agricultural development. This study is the first attempt to quantify the impacts of pesticide use on agricultural production and farmer's health in a major grain production region in China. To narrow the scope of analysis, however, rice in Zhejiang province was selected as the research focus. Rice accounts for about 40% of China's grain production and a major grain crop in Zhejiang province.

The overall goal of this paper is to have a better understanding of both positive and negative impacts of farm pesticide use on rice production and farmer's health. To achieve this goal, the paper is organized into the following sections: overview of the pesticide economy in China; trends of pest and weed related problems; profile of pesticide use in rice production and farmer's perception, knowledge, and pesticide use practices; determinants of pesticide adoption by farmers and impacts of pesticide use in rice production; impacts of pesticide use on the rice farmer's health; and summary of the findings of the study and their policy implications.

2.0 OVERVIEW OF PESTICIDE SECTOR IN CHINA

China's chemical pesticide industry has developed rapidly since the early 1950s. Pesticide production was about 1,000 metric tons (tons thereafter) only in 1950. It dramatically increased to 321,000 tons in 1970 (SSB), and reached a historic high of 537,000 tons in 1980 (Table 1). Insecticide production dominated the pesticide industry. More than three-fourths of all pesticides produced in China in the 1980s were insecticides. Fungicides accounted for about 10% of all pesticides produced, and herbicide, 6-7%.

The high toxicity and high residue of pesticides used in crops were major concerns of the country as the pesticides were dominated by organochlorines (OC) and organophosphates (OP) in the 1970s and the early 1980s. Of the 537,000 tons of pesticide produced in 1980, 64% were classified as "high toxicity and high residue" (MOA). The dramatic decline in the total supply of pesticides in the early 1980s reflected the considerable progress made in the pesticide industry with the introduction of less persistent and highly efficient compounds as substitutes for organochlorines in insecticides (e.g., BHC and DDT). Several policies and regulations on pesticide production and utilization were formulated in the early 1980s. These included the bans on the extremely hazardous OC and OP production in 1983, phasing out BHC (666) production in 1984, and reducing DDT production and allowing DDT to be used in non-crop production only. Since the mid-1980s, methamidophos, dimthypo, and parathionmethyl have been gradually replacing BHC, dichlorvos, dimethoate, and DDT as the dominant insecticides.

Table 1. Production, net import and total supply of pesticides (in active ingredients, 000 metric tons) in China, 1985-96

	Production	Net Import	Total Supply
1980	537.0	11.0	548.0
1985	204.3	6.6	210.9
1986	203.2	-11.1	192.1
1987	152.3	-11.8	140.5
1988	169.3	3.2	172.5
1989	196.8	7.2	204.0
1990	226.6	3.7	230.3
1991	253.4	1.0	254.4
1992	262.0	8.1	270.1
1993	230.7	-16.1	214.6
1994	263.7	-38.6	225.1
1995	349.0	-58.1	290.9
1996	381.2	-41.6	339.6

Sources: Trade data were from the State Statistical Bureau, Statistical Yearbook of China. Production data were from the Ministry of Chemical Industry, Statistical Yearbook of Chemical Industry.

Although the changes in the varieties of fungicides and herbicides produced in China had been less significant than those in insecticides, modifications have been made to improve the efficiency of both fungicides and herbicides and reduce their hazards.

Among the pesticides, herbicides registered the most significant increase in production (Table 2). Herbicide production increased by more than 4 times between 1985 (13,500 tons) and 1996 (60,300 tons) as the opportunity cost of labor increased. Other pesticides produced in China include plant growth regulators, acaricide, molluscicides, and rodenticides. By 1996, there were more than 1,100 pesticide factories in China.

China has been both an importer and exporter of chemical pesticides since the late 1970s. The growth rate of pesticides export has been higher than that of pesticide imports, enabling China to be a net pesticide exporter since the early 1990s. By 1997, China exported 87,600 tons of pesticides and earned US$309.4 million. Importing only 48,600 tons of pesticide in 1997, China had a trade surplus of US$143.6 million.

However while progress has been made in the pesticide industry since the mid-1980s, the increasing frequency of pest diseases since the mid-1980s has raised pesticide consumption. After a decline of annual pesticide supply from 548,000 tons in 1980 to 140,000 tons in 1987, the average pesticide available for agricultural use doubled again between 1987 and 1995. By 1996, the total pesticide supply reached 339,800 tons, which likely makes China the largest pesticide consumer in the world.

Table 2. Pesticide production (000 tons) for selected major varieties in China, 1980-96.

	1980	1985	1990	1995	1996
Insecticide		155.7	178.5	245.9	271.7
Top 4 varieties in 1980[a]	386.8	52.5	48.4	32.7	46.6
Top 3 varieties in 1995[b]	28.7	54.4	61.4	109.7	110.4
Fungicide		19.0	24.9	37.5	37.2
Top 3 varieties in 1980[c]	6.1	11.2	9.8	10.2	10.2
Top 3 varieties in 1995[d]	4.0	6.8	8.4	14.2	16.0
Herbicide		13.5	21.1	53.3	60.3
Top 3 varieties in 1980[e]	17.3	10.1	12.0	8.0	8.8
Top 3 varieties in 1995[f]	1.1	1.3	4.8	17.7	14.4

[a] 666 (BHC), Didiwei (Dichorvos), Leguo (Dimethoate), and DDT
[b] Jiaanlin (Methamidophos), Shachongshuang (Dimthypo), and Jiaji1605 (Parathionmethyl)
[c] Duojunling (Carbendazim), Jinggangmeisu (Validamycin A), and Yidaowenjing (MAFA)
[d] Duojunling (Carbendazim), Daishenmengxin (Mancozeb), and Yidaowenjing (MAFA)
[e] Wulufenna (PCP-Na), Chucaomi (Nitrofen), and 2,4-D
[f] Dingcaoan (Butachlor), Yicaoan (Acetochlor), and 2,4-D
Source: Data were from the Ministry of Chemical Industry, Chemical Industry Yearbook of China, various issues.

Pesticide use also differs significantly across the country's regions. Five provinces accounted for more than half of the national pesticide applications (Huang, et al., 2000). Among the provinces, Zhejiang has one of the most intensive pesticide uses. The rate of pesticide use in Zhejiang is more than double the national rate.

3.0 EXTENT OF CROP DISEASES AND PESTICIDE USE IN CROP PRODUCTION IN CHINA

3.1 Extent of Diseases and Efforts to Control the Diseases

The ratio of pest related epidemic area to the total crop sown areas was used to indicate the extent of pest problems. On the other hand, the proportion of weed epidemic areas to the total crop sown areas showed the extent of the weed problem.

Table 3 shows that, on the average, pests (insect and disease) occurred 1.3 times during one cropping season in 1988 in China[2]. This figure rose to 1.7 times in 1996, an increased of 31% over 8 years. Increases in the intensity of crop production and pesticide use (leading to a higher resistance by pests to pesticides) might explain most of the increases in the frequency of pest occurrences.

Table 3. The extent of pest (insect and disease) problems in Zhejiang and China, 1988-96.

Year	National		Zhejiang	
	Ratio of epidemic area to total crop sown area	Ratio of treated area to total crop sown area	Ratio of epidemic area to total crop sown area	Ratio of treated area to total crop sown area
1988	1.3	1.1	2.6	2.4
1989	1.5	1.2	2.8	3.0
1990	1.5	1.4	2.7	3.4
1991	1.6	1.5	2.8	3.4
1992	1.5	1.5	2.5	2.9
1993	1.6	1.7	3.0	3.2
1994	1.6	1.6	2.5	3.1
1995	1.7	1.8	2.8	4.5
1996	1.7	1.8	2.9	3.9

Source: Computed by authors based on the data from MOA, Agricultural Yearbook of China.

Zhejiang province, which had a higher multiple-cropping-index and higher pesticide use rate by farmers, had a much higher ratio of epidemic area to total crop sown area for both pest and weed, particular for insects and diseases. The data indicated that in 1988, the extent of insect and disease problems in Zhejiang (2.6) was twice as much as that for the country as a whole (Table 3). Although the rising trend of pest attacks in Zhejiang was less significant, the ratio of pest epidemic areas to total crop sown areas in Zhejiang (3.9) in 1996 was still more than 70% higher than that at the national level (1.7).

[2] The data reported in this section were based on a reporting system from the village to township and then to county, province and finally aggregating to a national level each year. This information was used internally by government to guide their decisions on policies related to pest control, and to assess the local organization's pest control effort and performance. Caution should be taken by the reader in the extent of pest related problem as there is an incentive for the local leaders to under-report the crop area actually affected by pest diseases, and over-report the crop prevention areas and crop loss abatement.

Weed problems were much less frequent than pest problems. For grain production at the national level, the ratio of weed epidemic areas to total grain sown areas was 0.35 (Table 4). But this level has increased significantly over the past 8 years. By 1996, the ratio rose to 0.57, 60% higher than that in 1988. On the average, the extent of weed problems in Zhejiang was about 50% higher than the national figures. The evidence of the increasing importance of weed problems in China confirms findings in the other countries (Rola and Widawsky, 1998).

Tables 3 and 4 show the efforts taken by farmers to prevent crop loss due to pest and weed problems. The higher ratios of areas with weed control treatment to total crop sown areas compared with those of epidemic areas since the early 1990s may reflect the fact of increasing availability of pesticides in the market and the ability of farmers to purchase pesticides. At the national level, the areas with control treatment had been larger than the estimated epidemic areas since the early 1990s (Table 4). Even if over-reporting of the prevention areas (a 20% rate of over-reporting was found by the case study) and under-reporting of affected areas are considered, the area affected by pests in recent years may be still higher than the areas with weed control treatment. The higher rate reflected by the weed control treatment areas in Zhejiang compared with the national average is consistent with the extent of pest attacks and the level of market development as well as income (credit constraint) in the province. A similar trend was found in weed control efforts exerted by the farmers (Table 4).

Table 4. Extent of grain areas affected by weed problems in Zhejiang and China, 1989-96.

	Ratio of epidemic area to total grain sown area (%)		Ratio of the areas with weed control treatment to total grain sown area (%)	
Year	National	Zhejiang	National	Zhejiang
1989	0.35	0.53	0.16	0.27
1990	0.38	0.56	0.19	0.34
1991	0.42	0.72	0.21	0.41
1992	0.40	0.66	0.24	0.46
1993	0.49	0.67	0.27	0.50
1994	0.51	0.87	0.36	0.67
1995	0.55	0.88	0.38	0.75
1996	0.57	0.74	0.41	0.65

Source: Computed by authors based on the data from MOA, Agricultural Yearbook of China.

3.2 Cost of Pesticide Use in Six Major Crops

Pesticide expenditures in all crop productions had increased considerably in the past decades. After deflating the current value of pesticide use by the retail price index of pesticide, the results indicate that the real cost of pesticide per hectare rose 2.5 times for rice, 3 times for wheat, and 4.8 times for maize in 1980-97. The real costs of pesticides per hectare of cropped areas increased by 1.5-2.6 times for fruits, vegetables, and cotton in the same period (Table 5).

The rates of pesticide application varied significantly among crops, reflecting that the extent of pest related problems differed across crops. On a per hectare basis, fruit and vegetable production used much more pesticides than the other crops. Cotton farmers applied 3 times more pesticides than rice farmers. In grain production, rice was the most intensive pesticide user. Per hectare rice production cost 231 yuan[3] of pesticide in 1997, nearly 3 times that of wheat and 4 times that of maize (Table 5).

Table 5. Pesticide use of major crops in China, 1980-97.

Year	Rice	Wheat	Maize	Cotton	Tomato	Cucumber	Apple	Orange
Per hectare pesticide cost (yuan at current prices)								
1980	29	8	4	85	na	na	349	347
1985	40	8	4	98	na	na	460	687
1990	103	31	16	305	297	373	1342	1695
1995	207	64	59	834	868	803	2058	1709
1996	224	99	56	721	759	899	1702	2083
1997	231	83	59	728	1041	1035	1888	1741
Per hectare pesticide cost (yuan at 1995 prices)								
1980	87	25	11	257	na	na	1048	1044
1985	118	23	12	292	na	na	1365	2041
1990	129	38	20	381	371	466	1677	2118
1995	207	64	59	834	868	803	2058	1709
1996	204	90	51	658	693	821	1554	1902
1997	214	77	55	674	964	958	1749	1613
Share (%) of pesticide cost in total material costs of crop production								
1980	5.8	1.9	1.0	13.1	na	na	36.1	17.8
1985	6.0	1.4	0.8	11.5	na	na	29.1	17.7
1990	7.5	2.7	1.6	18.1	4.8	6.3	29.3	25.6
1995	7.0	2.8	2.7	21.7	7.9	9.2	27.0	20.8
1996	6.9	3.5	2.3	18.5	6.7	9.4	20.4	21.5
1997	7.3	2.9	2.4	18.2	9.0	10.6	23.2	22.1

Note: Rural retail price index of pesticides was used to deflate the current value.
Source: State Economic Planning Commission.

[3] US$1 = 8.3 yuan

It is worth to note that the increase in pesticide use over time had been higher than that of other inputs in all crop productions. The cost share of pesticides in total material inputs rose from 5.8% in 1980 to 7.3% in 1997 in rice production, 1.9% to 2.9% in wheat, and 1.0% to 2.4% in maize. The most significant increase in pesticide cost share occurred in cotton production, rising from 13.1% in 1980 to 21.7% in 1995.

On the aggregate basis, rice was the largest pesticide user. National data showed that rice farmers spent more than 7.3 billion yuan for chemical pesticides to control pest problems in 1997 (Table 6). This was followed by apple (5.4 billion yuan), cotton (3.3 billion yuan), wheat (2.4 billion yuan), orange (2.3 billion yuan), and maize (1.4 billion yuan). For these 6 crops altogether, farmers spent about 22.2 billion yuan (or US$ 2.67 billion) for pesticides. These 6 crops accounted for about 61.5% of the total crop areas in the past 2 decades. Using a similar rate of pesticide use to the rest of crops that are not included in Table 6, the study estimated that currently Chinese farmers may spend as much as 36.1 billion yuan (US$ 4.34 billion) annually for chemical pesticides. In 1992, Japan was the world's largest pesticide consumer with a total amount of US$ 3.5 billion (Wood Mackenzie Co., Ltd., 1993, as cited in USAID 1994 and Yudelman et al., 1998). Although there are no comparable data available for Japan in 1997, estimates showed that, based on China's current rate of pesticide use, it is likely to have been the largest pesticide consumer in the world since the mid-1990s.

Table 6. Total pesticide expenditure for major crops of China, 1980-97.

Year	Area	Six Major Crops						
	Share of the 6 crops (%)	6 crops	Rice	Wheat	Maize	Cotton	Apple	Orange
Million yuan at current prices								
1980	61	2070	981	246	76	420	257	90
1985	60	2824	1275	228	69	506	398	348
1990	63	10397	3412	946	343	1705	2192	1799
1995	61	22223	6359	1840	1346	4524	6079	2075
1996	62	22472	7024	2923	1374	3403	5083	2665
1997	61	22154	7347	2498	1402	3268	5359	2280
Million yuan at 1995 prices								
1980		6227	2950	738	230	1263	774	272
1985		8384	3785	677	205	1502	1182	1035
1990		12990	4263	1182	429	2130	2738	2248
1995		22223	6359	1840	1346	4524	6079	2075
1996		20522	6415	2669	1255	3108	4642	2434
1997		20519	6805	2313	1298	3027	4964	2112

Million US$ converted at official exchange rate								
1980		1382	655	164	51	280	172	60
1985		962	434	78	23	172	136	119
1990		2173	713	198	72	356	458	376
1995		2661	762	220	161	542	728	248
1996		2703	845	352	165	409	611	321
1997		2672	886	301	169	394	647	275

Note: Rural retail price index of pesticides was used to deflate the current value.
Source: State Economic Planning Commission for cost of production data, crop areas data used in computing the total pesticide cost and exchange rates were from SSB.

4.0 FARMERS' KNOWLEDGE, ATTITUDES, AND PRACTICES REGARDING PESTICIDE USE

It is often observed that farmers, the major pesticide users, are not fully aware of the risks related to pesticide use (Rola and Pingali, 1993). Misuse and overuse of pesticides are often observed in the developing countries (Warburton et al., 1995; Heong et al., 1995; Yudelman, 1998). A clear understanding of farmers' knowledge, attitudes, and practices regarding pesticide use is the first step toward understanding the reasons for overuse of pesticides by farmers.

4.1 Farmers' Perception of Crop Loss due to Pest

Farmers' perceptions of pest-related yield loss are important as such perceptions will have a direct effect on the amount of pesticides used by the farmers. Many literature on pest -related yield loss show various farmers' misperceptions, which often result in overuse of pesticides (Tiat, 1997; Mumford 1981, 1982; Norton and Mumford 1983; Pingali and Carlson 1985; Carlson and Mueller 1987; Rola and Pingali 1993).

Table 7 summarizes the studies that showed rice yield losses due to insects, plant diseases, weeds or all pest-related yield losses in Asia. Cramer (1967) reported that all pest-related yield losses in Asia were about 55%, of which 34% were due to insects, 10% due to diseases, and 11% due to weeds. Ahrens et al. (1982) reported a slightly lower rate of yield losses due to insects (24%) for East and Southeast Asia. On the other hand, Pathak and Dhaliwal's study (1981) in the Philippines recorded a higher rate (35%-44%) of insect related losses. Although the yield losses due to insect-related problems varied from one study to another, most studies reported insect-related yield losses of a similar magnitude, ranging from 20% to 40% in most cases.

Table 7. Crop loss due to aggregate damage of pests in selected countries.

Country	Source of loss	Estimated crop loss (%)	Author	Year
Asia	Insects	34	Cramer	1967
	Diseases	10	Cramer	1967
	Weed	11	Cramer	1967
East & Southeast Asia	Insects	24	Ahrens et al	1982
Philippines	Insects	20-25	Pathak and Dyck	1973
Philippines	Insects	16-30	Way	1976
Philippines	Insects	35-44	Pathak and Dhaliwal	1981
Philippines	Insects	29	Kalode	1987
Philippines	Insects	18	Litsinger et al	1987
Philippines	All pests	35	Waibel	1990
Thailand	All pests	50	Waibel	1990
India	Insects	35	Way	1976
Sri Lanka	Insects	20	Fernando	1966
China	All pests	42	This report	1999

Sources: All figures were from a summarized table in Rola and Pingali (1993) and Waibel (1990) except for China, which were from the yield trials of this study.

In order to justify the pest-related yield losses in this study's sample areas, with help from the local plant protection bureau, a yield constraint trial was conducted in Anji, one of the studied counties, to evaluate the impacts of pest-related yield losses (insects, diseases, and weeds).[4] The results showed that rice yield loss was about 41-43% of production when no pesticide was applied (the last row, Table 7). The figure was lower than those found by Cramer (55%, 1967), but was close to the average results for the Philippines and Thailand in a more recent study by Waibel (1990).

But even assuming that the true pest-related yield loss was about 42% in the studied areas, the figure was still much lower than the local farmers' estimates.[5] On the average, the farmers estimated rice yield losses due to pest problems to be 75.6% of the production (Table 8). It is worth to note that farmers' perception of variation of crop loss due to pest diseases was small (ranging from 70.2% in Zhengbei to 80.8% in Yushanwu and relatively small

[4] The experiment was conducted in 1998 using the most common variety (Xianyou 63) adopted by the local farmers in Yushanwu village, the same village where the survey was conducted and in the same rice production season. The total experiment area was 4 mu (or 0.267 hectare, 15 mu = 1 hectare), which was divided into 4 plots with 2 cross classifications: with and without pesticide uses, and with chemical fertilizer (no organic fertilizer) and with organic fertilizer (no chemical fertilizer).

[5] There were 100 samples, with 25 farmers from each village, 2 villages from each county. The surveys were conducted in Jiaxing and Anji counties, Zhejiang province in 1998.

standard errors within village, Table 8), indicating that the perception of high yield losses was very common among the farmers in the study.

Table 8. Farmers' perception and field experiment on crop loss due to pest problems in rice production in the sampled areas of Zhejiang province.

	Crop loss estimate (%)	Standard error
Total sample	75.6	19.6
Zhengbei village	70.2	18.5
Yangzhuang village	74.3	18.9
Yushanwu village	80.8	17.6
Shuikou village	77.0	22.6
Experiment in Yushanwu	41.9	

Sources: All data were based on authors' survey except for experiment data in Yushanwu, which were provided by Anji Agricultural Bureau, Zhejiang province.

While there was no significant difference in the yield loss perceptions of farmers with less than 9 years of education (lower than high school), farmers with higher education (more than 9 years, mainly high school) had a lower yield loss perception (Table 9). On the other hand, no significant differences on farmers' perceptions of rice yield losses by ages were found.

Table 9 also shows the farmers' perceptions on yield losses due to pest-related problems by land endowment and income. No formal conclusive results could be made from the data presented. The differences in yield losses perceptions by farmers were very marginal among various land endowments (per capita farmland) and income groups.

The overestimation of pest-related yield losses by farmer has been often mentioned in the literature, but few of them have carefully investigated the basis used for the estimates. Based on this study's intensive survey of 100 rice farmers in Xiaxing and Anji counties of Zhejiang province, the econometric analysis of farmers' perception on yield losses due to pest-related diseases showed that education, farm size, occupation or source of income, and village level extension system were major determinants of farmers' yield loss perception (Huang, et al., 2000).

4.2 Farmers' Knowledge of Pest Management

Farmers' knowledge of pest management was examined based on their awareness of types of pesticides, pest enemies, alternative pest management measures, and the changes in the extent of pest problems over time. Although the kinds and amount of pesticide applied by farmers have increased significantly over the last 2 decades, farmers' knowledge of pest management was lower than expected. Among 100 respondents, 34 farmers could not tell any differences in hazards caused by the pesticides they used (Table 9). Those who replied they know the pesticide hazard (66 farmers) had very minimal knowledge.

Table 9. Perceived pest related yield losses (%) and farmers' (respondents') characteristics in Jianxing and Anji counties of Zhejiang province, China.

	Jianxing	Anji	Total
All samples	72.2 (50)	78.9 (50)	75.6 (100)
By age: < 40 years	73.9 (19)	76.0 (14)	74.8 (33)
40-50 years	64.8 (14)	83.9 (22)	76.4 (36)
> 50 years	76.5 (17)	73.9 (14)	75.3 (31)
By sex: Male	71.1 (42)	79.5 (48)	75.5 (90)
Female	78.4 (8)	65.0 (2)	75.7 (10)
By education: Primary or less	72.3 (27)	81.0 (35)	77.2 (62)
Middle school	74.4 (17)	78.6 (11)	76.1 (28)
High school	65.8 (6)	61.0 (4)	63.9 (10)
Per capita land			
< 1.25 mu	75.2 (21)	78.3 (12)	76.4 (33)
1.25-1.75 mu	70.1 (20)	81.5 (13)	74.6 (33)
>1.75	70.0 (9)	77.8 (25)	75.7 (34)
Per capita income			
<3000 yuan	71.8 (14)	74.2 (19)	73.2 (33)
3000-5000 yuan	67.7 (15)	79.7 (18)	74.2 (33)
>5000	75.8 (21)	84.6 (13)	79.2 (34)
Agricultural share in total income			
<15%	71.0 (20)	80.4 (9)	73.9 (29)
15-30%	74.3 (15)	78.2 (17)	76.4 (32)
>30%	71.8 (15)	78.8 (24)	76.1 (39)

Note: Figures in parentheses are the number of samples. The total sample was 100, with 25 farmers from each village, 2 villages from each county. The surveys were conducted in Jiaxing and Anji counties, Zhejiang province.

About two-thirds of farmers (65) did not know that pests have "enemies", and about half of them never heard about integrated pest management (IPM). This was surprising since Anji and Jiaxing have been sites of ecology-agricultural production experiments for a long time.

No significant difference in farmers' knowledge of pest management was found between Jiaxing and Anji. Education, however, was found to have a positive link with farmers' knowledge of pesticide hazard to the environment and human health, and of integrated pest management (Table 10).

Most of the farmers perceived that the kinds and frequency of crop insects and diseases had not change over the past 15 years. Among 100 farmers interviewed, only 9 and 12 farmers perceive the increasing trend of insect and disease problems, respectively, in the past 15 years (Table 11).

Analysis of the data on education, sex, and location showed no significant difference on farmers' perceptions of the changing trends of pest diseases over the past 15 years. The small sample of female farmers limited the study from making any conclusion on gender bias. However, the 10 females interviewed all responded that there had been no change in the crop insect and diseases in their fields (Table 11).

Table 10. Farmers' knowledge of pest management.

	Average	By education		By sex	
		≤6 years	>6 years	Male	Female
All samples					
Know about pesticide hazards					
-- Yes	66	36	30	63	3
-- No	34	26	8	27	7
Know about pest enemies					
-- Yes	35	27	8	30	5
-- No	65	35	30	60	5
Heard about IPM					
-- Yes	49	28	21	48	1
-- No	51	34	17	42	9
Jiaxing county					
Know about pesticide hazards					
-- Yes	30	14	16	28	2
-- No	20	13	7	14	6
Know about pest enemies					
-- Yes	13	8	5	9	4
-- No	37	19	18	33	4
Heard about IPM					
-- Yes	20	9	11	20	0
-- No	30	18	12	22	8

Anji county					
Know about pesticide hazards					
-- Yes	36	22	14	35	1
-- No	14	13	1	13	1
Know about pest enemies					
-- Yes	22	19	3	21	1
-- No	28	16	12	27	1
Heard about IPM					
-- Yes	29	19	10	28	1
-- No	21	16	5	20	1

Note: The figures in the table are the number of farmers. The total sample was 100, with 25 farmers from each village, 2 villages from each county. The surveys were conducted in Jiaxing and Anji counties, Zhejiang province.

Table 11. Farmers' perceptions of the kind and frequency of pest diseases over past 15 years.

	Average	By schooling		By sex	
		≤6 years	>6 years	Male	Female
Total Samples					
Insect					
No changes	88	55	33	78	10
Declining	0	0	0	0	0
Increasing	9	6	3	9	0
Do not know	3	1	2	3	0
Disease					
No changes	83	55	28	73	10
Declining	2	1	1	2	0
Increasing	12	5	7	12	0
Do not know	3	1	2	3	0
Jiaxing county					
Insect					
No changes	46	27	19	38	8
Declining	0	0	0	0	0
Increasing	2	0	2	2	0
Do not know	2	0	2	2	0
Disease					
No changes	44	26	18	36	8
Declining	0	0	0	0	0
Increasing	4	1	3	4	0
Do not know	2	0	2	2	0

Anji county					
Insect					
No changes	42	28	14	40	2
Declining	0	0	0	0	0
Increasing	7	6	1	7	0
Do not know	1	1	0	1	0
Disease					
No changes	39	29	10	37	2
Declining	2	1	1	2	0
Increasing	8	4	4	8	0
Do not know	1	1	0	1	0

Note: The figures in the table are the number of farmers. The total sample was 100, with 25 farmers from each village, 2 villages from each county. The surveys were conducted in Jiaxing and Anji counties, Zhejiang province.

4.3 Farmers' Attitudes on Recommended Pesticide Usage

The township plant protection stations normally recommend the pesticide to be used for pest control in the sample villages. In Zhengbei, one of the surveyed villages, farmers received a written notice (1-2 pages) from the technician at the township plant protection station on every pesticide to be used in controlling pest diseases in rice production. The notice included the timing of pesticide application and the kinds of pesticide to be used for insects or diseases. The other three villages did not have such formal notice, however, similar information was passed to farmers through radio broadcasts.

However, most farmers did not believe the recommendations and the instructions written on the pesticide products. They considered the recommendations as under-dosage. Only 30 (among 100) farmers considered the recommendation as "adequate" (Table 12). But when farmers applied the pesticides in their fields, only 14 farmers followed the instructions on the label. The other farmers applied more than the recommended dosage. The proportion (8 out of 10, or 80%) of females who considered the recommended amount of dosage as "too low" was higher than the males (51 out of 90 or 57%).

Farmers' perception of high crop yield loss due to pest and their doubts on the technician's recommendation and pesticide prescription provided by pesticide industry (label) directly related to farmers' over use of pesticides. Risk consideration is often cited in the literature as a major reason for farmers' pest management behavior. In this study, less than half of the farmers obtained information on pest management from technicians and pesticide labels (Table 13). On the other hand, traditional information channels (e.g., own experience, friends, relatives), pesticide salespersons, and others accounted for 54% of the farmers' sources of information.

Table 12. Farmers' attitudes on recommended pesticide usage

Question		By schooling		By sex	
	Average	≤6 years	>6 years	Male	Female
How do you evaluate the recommended dosage given in labels of pesticide products?					
-- Adequate	30	23	7	28	2
-- Too little	59	32	27	51	8
-- Too much	4	2	2	4	0
-- Do not know	7	5	2	7	0
Do you apply more/less pesticide than recommended dosage given in labels of pesticide products?					
-- About same levels	14	11	3	13	4
-- Apply more	84	50	34	75	9
-- Apply less	0	0	0	0	0
-- Do not know	2	1	1	2	0

Note: The figures in the table are the number of farmers. The total sample was 100, with 25 farmers from each village, 2 villages from each county. The surveys were conducted in Jiaxing and Anji counties, Zhejiang province.

Table 13. Sources of information on pest management.

	Pesticide label	Technician	Own experience	Friends & relatives	Pesticide salespersons	Others
Total sample	8	38	25	4	18	7
-- Jiaxing	5	54	19	5	13	3
-- Anji	10	23	30	2	24	11

Note: The figures in the table are the number of farmers. The total sample was 100, with 25 farmers from each village, 2 villages from each county. The surveys were conducted in Jiaxing and Anji counties, Zhejiang province.

4.4 Farmers' Pesticide Purchasing Behavior

Farmers' response to pesticide prices: One of the most interesting findings from these experiments was the farmers' response to pesticide price changes. Of the 100 farmers interviewed, only 5 farmers said they would reduce their pesticide use by 22% if the pesticide price were raised by 50% (Table 14). Even if the pesticide prices were to be doubled, only two farmers would reduce their pesticide use. Further increasing the pesticide price up to 200% would still not have any effect on the decision of 87 farmers regarding their level of pesticide use (Table 14). On the average, there would be only 1.1% reduction due to a 50% increase in pesticide price. A similar result was found when farmers were asked to respond to reductions in pesticide prices. This price response was much lower than that in a similar study in the Philippines (Rola et al. 1988). Rola et al. found that the decision on pesticide use by about 60% of rice farmers was not affected by any changes in pesticide prices. The present study's interview with farmers on pesticide use revealed that the inelasticity of pesticide use response to price changes was mainly due to the farmers' exceptionally high level of expected yield loss due to pests, ranging from 30% to 100% with an average of 76%.

Table 14. Farmers' response to hypothesized pesticide price changes.

Pesticide price change	All farmers	No change in pesticide use	with changes in pesticide use	Change in pesticide use (%)	
				All farmers	w/ changes
Increase by:					
50%	100	95	5	-1.10	-22
100%	100	93	7	-1.61	-23
200%	100	87	13	-9.10	-70
Decrease by:					
50%	100	97	3	+0.69	+23
75%	100	95	5	+1.90	+38

Note: The total sample was 100, with 25 farmers from each village, 2 villages from each county. The surveys were conducted in Jiaxing and Anji counties, Zhejiang province.

Farmers' preference on pesticide brand and occurrence of fake pesticides. With various kinds/brands of pesticides available in the market and frequent reports of fake pesticides (most had low quality or were not as effective as they should be) sold in the market, more than half of the farmers (51%) did not have any brand preference. Sixteen farmers reported having applied fake pesticides at least once in the past 15 years. Twenty-one farmers perceived the proliferation of fake pesticides as becoming more severe over time.

Sources of pesticides. On the average, each household purchased more than 15 kg of pesticides within one year. About 54% of the pesticides were purchased from the nearby Agricultural Input (Materials) Cooperative and Agricultural Technology Extension Station at both county and township levels. With the recent liberalization of pesticide retail, private trade has become a dominant player in the pesticide market. Private traders provided 46% of the total pesticides used by the farmers.

4.5 Safety and Storage Practices

Farmers' knowledge of pesticide residue. Farm pesticides are components artificially introduced into and generally incompatible with agricultural ecosystems. When applying pesticides, only about 20-30% of them are absorbed by the crops; the rest are left in the environment. However, many farmers did not have any knowledge of the pesticides' impact on the environment. Nearly one-third (31%) of the farmers did not realize that pesticide residues may remain in paddy grains. The more educated farmers were more aware of the pesticide residue problem. Most of the farmers (74%) who completed mid-school or higher education knew pesticide residues remain in rice paddy.

Pesticide storage, disposal, and application practices. The survey found that 90% of farmers placed the pesticide bottles in a special location inside their houses where it would be difficult for children to reach (Table 15). The remaining 10% placed the bottles in unsafe places such as on the ground or mixed with other kinds of bottles without any safety precaution.

Disposal of empty pesticide bottles is also a safety concern. Many farmers (43%) disposed of the empty bottles in the river, field, and outside the house (Table 15). About 20% of the farmers kept the empty bottles for other uses, while one-third sold the bottles to bottle collectors. In the survey, disposal of remaining pesticide in sprayer presented a lesser problem than the disposal of empty bottles. Only about 5% of the farmers dumped the remaining pesticide into river and other places that may hurt human and animal health.

Sprayer maintenance. All farmer-respondents had their own sprayers. But almost half (48%) of them reported that their sprayers had leakage problem, of which 15% were severe cases. Only those with severe leaking sprayers planned to purchase new ones in the near future. Since sprayers are cheap (about 70-80 yuan, or US$9), farmers normally purchased new sprayers instead of repairing them when they get damaged.

The survey also found that only 60% of the farmers washed their sprayers every after use (Table 15). Most of them washed the sprayers in the river (94%). On the other hand, 24% of the farmers rarely or never washed their sprayers.

Safety measures. Most farmers sprayed pesticides away from the wind. Although almost all users were partially covered with protective clothing (long sleeves or/and long pants), none of them used masks. Due to the lack of awareness of pesticide hazards, 19% of the farmers normally did not take a bath after pesticide application; 13% commonly washed their face only and 6% washed their hands only.

Although farmers' knowledge of pesticide safety issues was better than pest management, it was also very limited and varied with the farmer's level of education. The farmers' limited knowledge of pest management and high risk aversion in pest control resulted in their over estimation of crop yield losses due to pests and inelasticity in farmers' pesticide use response to pesticide price changes. Efforts to convince farmers to reduce their pesticide use will mainly rely on the factors that could significantly reduce the farmers' risk aversion. These may include pest management related information, education, training, and extension services.

Table 15. Farmers' pesticide storage and disposal practices.

	Total	Male	Female
Pesticide storage after purchase [a]:			
Safe storage practices (%)	90	100	89
Unsafe storage practices (%)	10	0	11
Disposal of empty pesticide bottles:			
Sold (%)	31	28	60
Disposed of in river, field, outside house (%)	43	45	20
Keep for other uses (%)	19	20	20
Continued for pesticide storage or buried (%)	7	7	0
Disposal of remaining pesticide in sprayer:			
Continually used in the same field (%)	83	84	70
Dumped in the field (%)	12	10	30
Dumped in river and other place (%)	5	6	0
Sprayer use practices:			
Wash every time after use (%)	60	60	60
Wash most of time (%)	16	17	10
Wash rarely or never wash (%)	24	23	30
Places of wash sprayer			
River (%)	94	94	89
Paddy field (%)	3	2	11
Other places (%)	3	4	0

[a] Safe storage practice = the bottle is placed in a special place inside the house where it is difficult for children to reach; unsafe = all other practices.

5.0 CHEMICAL PESTICIDE ADOPTION AND ITS IMPACTS ON RICE PRODUCTION

There is a wide debate on the contribution of pesticides to crop production (e.g., reducing losses) and the negative impacts of their use on the environment and human health[6]. For example, Oerke et al. (1995) reviewed a large number of literature that show that chemical pesticides have significantly reduced pest related crop yield losses. On the other hand, there are also a substantial number of literature that show the negative impacts of chemical

[6] A comprehensive review of the literature could be found in Oerke et al., 1995; Pingali and Roger, 1995, Pimentel, D. and H. Lehman. 1992,and Yudelman et al. (1998).

pesticides. Several economic studies have questioned whether current patterns of pesticide use are economically and socially efficient (e.g., Pimentel, D. and H. Lehman, 1992; Pingali and Roger, 1995; Yudelman et al., 1998). Some studies showed that the costs (both economic and social costs) related to pesticide use in crop production were higher than the gains from the reduction of crop yield losses (e.g., Pingali and Roger, 1995).

While studies of pesticide productivity are relatively common, few researchers have assessed the farmer's pesticide adoption behaviors. In fact, there has been no study on the impacts of chemical pesticide in China except for a recent study by Widawsky et al. (1998). The latter focused on pesticide productivity and host-plant resistance in China. It showed that under intensive rice production systems in Jiangsu and Zhejiang provinces in eastern China, pesticide productivity was low compared with the productivity of host-plant resistance. Moreover, they found that returns to pesticide use were negative at the margin.

To achieve optimal pesticide use in the economic sense, answers to the following questions are essential to formulate effective policies and regulations on pesticide uses: What is the extent of over use of pesticides by farmers? What are the major factors that affect farmer's pesticide applications? What is the productivity of pesticide use in rice production?

This section has three objectives: 1) to examine the extent of pesticide use at the farm level in rice production; 2) to investigate the determinants of pesticide adoption by rice farmers; and 3) to estimate the productivity of pesticide use in rice production. This section is organized as follows: discussion on rice production and inputs in the sample households and pesticide adoption in rice farming; and then development of an empirical model to determine the factors of pesticide adoption behaviors and impacts of pesticide on rice production. Based on the 100 primary rice farms survey, rice production function with endogenous pesticide adoption model was estimated.

5.1 Rice Production in the Sample Households

The average farm size (0.50 ha) in the sample was slightly smaller than the country average (0.57 ha). Farmers allocated more than 80% of their land to grain production. Rice was the most important grain and accounted for 58% of the total crop area (Table 16).

Table 16. Importance of rice production in the surveyed farms by village.

	4 villages	Zhengbei	Yangzhuang	Yushanwu	Shuikou
Farm size (ha)	0.50 (0.33)	0.51 (0.29)	0.47 (0.47)	0.50 (0.19)	0.54 (0.32)
Rice area (ha)	0.50 (0.39)	0.63 (0.29)	0.66 (0.58)	0.23 (0.10)	0.46 (0.28)
Rice share in total crop area (%)	58 (17)	60 (7)	64 (8)	40 (19)	68 (17)
Share of double-season rice in total rice area (%)	37 (41)	69 (32)	80 (15)	0 (0)	0 (0)
Share of single-season rice in total rice area (%)	63 (41)	31 (32)	20 (15)	100 (0)	100 (0)
Proportion of paddy land (%)	86 (15)	91 (6)	92 (7)	68 (17)	93 (7)

Note: Figures in parentheses are standard errors. Data were from 100 households in 4 villages of Jiaxing and Anji counties in Zhejiang province.

In the two villages of Jiaxing county, rice was planted under a double-season rice cropping system, which accounted for 69% of the total rice area in Zhengbei village, and 80% in Yuangzhuang village. In these two villages, the common cropping patterns were rice-rice and cash crop-wheat. In Yushanwu and Shuikou villages of Anji county, rice was planted under a single-season rice cropping system. The common cropping patterns in Anji county were rice-wheat, rice-rape seed, and cash-cash crops.

Rice yield in the sample households ranged from about 6 tons/ha to 7.3 tons/ha, which was slightly higher than the national average. The yields of single-season rice (6.34-7.30 tons/ha) were generally higher than those of double-season rice (5.96-6.57 tons/ha) because of the longer growing period of the former (Table 17).

Table 17. Rice yield (ton/ha) in the surveyed farms, Zhejiang, China, 1998.

	Double-season early rice		Double-season late rice		Single-season middle rice		Single-season late rice	
Village	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
Zhengbei	6.08	0.84	6.57	0.93			7.30	1.05
Yangzhuang	5.96	0.51	6.25	0.80			6.66	0.94
Yushanwu					6.34	1.33	6.24	1.07
Shuikuo					6.63	0.76	6.21	0.70

On the average, farmers used 179 labor days and 282 kg of fertilizers for every hectare of rice crop. An imbalance in chemical fertilizer elements (N:P:K) found by previous studies (Huang et. al., 1994 and 1995) was also evident in this study. The ratio of N:P:K used was about 14:1:4; obviously, phosphate and potash fertilizers were relatively underused compared with nitrogen.

The average pesticide use per hectare reached 27.67 kg for each rice growing season, which cost the farmers 287 yuan (or US$ 34.7). As the surveys were simultaneously conducted in the four villages, it was expected that, for the cross section data, the prices paid by farmers for individual pesticides would be the same or similar for all farmers in the surveyed areas.[7] However, there was a large difference in the prices of the different pesticides, reflecting the differences in their quality. The mixed average price (a better term might be "quality index") of all pesticides was 10.89 yuan/kg, with the price ranging from 3.70 yuan/kg to about 50 yuan/kg with a standard error as high as 5.07 (Table 18).

Table 18. Per hectare input in rice production in the surveyed farms, Zhejiang, 1998.

	Mean	Standard error
Labor (days/ha)	179.23	66.05
Fertilizer (kg/ha)	282.37	106.36
Pure N (kg/ha)	205.48	71.66
Pure P (kg/ha)	15.02	28.63
Pure K (kg/ha)	61.87	50.26
Pesticide use:		
Volume (kg/ha)	27.65	11.82
Cost (yuan/ha)	287.14	142.60
Average mixed price (yuan/kg)	10.89	5.07

5.2 Adoption of Pesticide Use in Rice Farming

Rice farmers in the sample areas applied pesticides 8.8 times per year for rice production (Table 19). Disaggregating the farmers into different groups based on farm and farmers' characteristics showed that pesticide application levels were affected by sex, age, and sources of pest management information (Table 19). Because the variables presented in Tables 19 indicated a strong linkage with farmer's perception of rice yield loss due to pest-related diseases, (their impacts on pesticide use might be through farmer's perception variable), testing the impacts of these variables required a more sophisticated model, which is discussed in the next section.

[7] The prices of individual pesticides obtained from both the local pesticide retail survey and farmers' survey indeed showed no significant price variations (only 1-3%) for the same kind of pesticide.

Compared with other Asian countries, farmers in the surveyed areas applied exceptionally large amounts of pesticide in rice production. Average pesticide application per hectare rice (per season) amounted to 27.7 kg or about 12-14 kg of active ingredients (Table 20). This was similar to the usage level in Japan (14.3 kg of active ingredients) and the Republic of Korea (10.70 kg of active ingredients), but much higher than the rest of Asian countries (Barker and Herdt, 1985).

On the average for each season (not each year as some farmers planted two seasons of rice), farmers applied pesticides 8 times: about 3 times during seedling period and 5 times in the field (after transplanting, Tables 20 and 21). Table 20 also shows the variations of pesticide use among villages. The differences between villages could be attributed to the differences in rice cropping patterns, quality of agricultural extension service, location specific fixed factors, etc. Lower values of pesticide use in this table compared with the figures in Table 19 were due to the higher weight given to farmers planting single-season rice, which had a higher pesticide application rate.

Table 19. Pesticide use in rice production, farmers' characteristics and application information sources in the surveyed farms in Zhejiang, China, 1998.

Farmer's group	Sample size (n)	Pesticide use per hectare per year		
		Times (n)	Dosage (kg)	Cost (yuan)
All farmers	100	8.8	29.5	318.7
By sex				
Male	95	8.9	29.9	322.8
Female	5	6.3	22.8	242.2
By age				
< 40	33	8.8	30.2	304.4
= 40-50	36	8.8	28.2	327.2
≥ 50	31	8.7	30.4	324.2
By years of schooling				
≤ 6 years	62	9.0	30.8	330.4
> 6 years	38	8.4	27.5	299.7
By per capita land				
< 1.25 mu	33	7.9	29.1	312.0
= 1.25-1.75 mu	33	8.5	25.3	275.2
> 1.75 mu	34	9.8	34.1	367.6
By information sources of pest management				
ATES	39	9.0	30.7	340.1
Others	61	8.4	27.8	285.4

Note: Data were from 100 households in 4 villages of Jiaxing and Anji counties in Zhejiang province. ATES – Agricultural Technology Extension Station. "Others" include own experience, other farmers, pesticide retails etc.

Table 20. Pesticide use in rice production in the surveyed farms in 1998.

Village	Sample size (n)	Pesticide use per hectare per season		
		Times (n)	Dosage (kg)	Cost (yuan)
All 4 villages	200	8.0	27.7	287.1
Zhengbei	68	7.3	23.7	206.4
Yangzhuang	72	7.0	26.6	284.3
Yushanwu	28	9.2	32.7	436.7
Shuikou	32	10.5	33.9	334.1

Note: Data are summary of double-season early rice, double-season late rice, single-season middle rice, and single-season late rice. The effective sample size was 200; that is, on the average each farm planted 2 kinds of rice. The conversion rates of "dose" to active ingredients varied among the pesticides applied by farmers. But the average conversion rate was about 45%. The figures in this table differed slightly from Table 20, which used the number of farms as sample base unit.

During the field survey, the local farmers reported that the current frequency of pesticide application in the 1970s was only about 4-5 times for each rice growing season. The frequency of pesticide application significantly increased in the early 1980s when the collectively owned land was distributed to individual households. The reform increased the production incentives of farmers (Lin, 1992; Fan, 1991; Huang and Rozelle, 1996), although there is also evidence that China's technology generation and extension systems may have been weakened after the reform, which could have resulted in an increase in the cost of technology adoption (Lin, 1991; Huang and Rozelle, 1996).

The frequency of pesticide application in Zhejiang province was about 2-3 times higher than the average for some Asian countries (Table 21). Although the protection rate of pesticide price was relatively low in China, pesticide expenditure per hectare was also one of the highest in Asian countries.

Table 21. Frequency and cost of pesticide application, Zhejiang, China, 1998.

Region/Country	Number of applications (n)	Expenditure (US$/ha)
India	2.4	24.9
Philippines	2.0	26.1
Indonesia	2.2	7.7
Northern Vietnam	1.0	22.3
Southern Vietnam	5.3	39.3
China, 4 villages (this study, rice)	8.0[a]	38.5

[a] 3 in seedling period and 5 after transplanting

Source: Data for others countries were for 1990-91 as reported in Dung and Dung, 1999.

Pesticide use also differed by rice cropping system. While double-season rice used much higher dosage of pesticides on an annual basis (i.e., add-up double-season early and late rice), on a per crop season basis, pesticide use in single-season rice was higher than that in double-season rice (Table 22). The lower level of pesticide applications in double-season early rice was mainly due to fewer applications of pesticides during the rice seedling period and fewer pest-related problems in April to June. The longer the rice growing period such as single-season middle and late rice, the higher the level of pesticide use (Table 22).

Table 22. Pesticide use by rice season in the surveyed farms, 1998.

Rice season	Sample size (n)	Pesticide use per hectare		
		Times (n)	Dose (kg)	Cost (yuan)
All rice	200	8.0	27.7	287.1
Double-season early rice	47	5.7	20.6	174.5
Double-season late rice	47	8.7	28.4	288.9
Single-season middle rice	35	10.0	31.0	325.0
Single-season late rice	71	7.9	30.2	341.8

The levels of pesticide application were also found to have a positive relationship with farmer's perceived yield losses due to pest attacks (Table 23). For example, the pesticide application dosage and costs of farmers with less than 70% of rice yield loss perception were about 15% and 24%, respectively, lower than those of farmers with more than 80% of rice yield loss perception (26.2 kg vs 31 kg, 275.1 yuan vs 342.1 yuan) (Table 23).

Table 23. Pesticide adoption and farmers' perceptions of rice yield loss due to pest in the surveyed farms of Zhejiang, 1998.

Farmer' group	Sample size (n)	Pesticide use per hectare		
		Times (n)	Dosage (kg)	Cost (yuan)
All farmers	100	8.8	29.5	318.7
Perceived yield losses < 70%	28	7.8	26.2	275.1
= 70-80%	37	9.2	30.1	329.7
> 80%	35	9.0	31.0	342.1

Note: Sample refers to 100 farm households

5.3 Pesticide Adoption and Rice Production Model

Damage Control Production Function

To estimate the impact of chemical use on rice productivity, a production function approach was used. However, the roles of pesticide and other inputs on rice production differ by nature. Inputs such as fertilizer and labor were treated as "normal" inputs that contribute to yield increase, while pesticide was a damage abatement input. The production function was a combination of yield loss and output that was recoverable by limiting this loss with damage control inputs. Following the works by Headley (1968) and Lichtenberg and Zilberman (1986), a damage abatement function was incorporated into the traditional models of agricultural production.

The nature of damage control suggests that the observed crop yield, Y, can be specified as a function of both standard inputs and damage control measure. That is:

$$(1) \qquad Y = f(X)\, G(Z),$$

where X is a vector of standard inputs such as labor, fertilizer, and other inputs. $G(Z)$ is a damage abatement function that is a function of the level of control agent, Z (e.g., pesticide use level). The abatement function possesses the properties of a cumulative probability distribution. It is defined on the interval of [0, 1]. $G(.) = 1$ indicates a complete abatement of crop yield losses due to pest attacks with a certain high level of control agent, while $G(.) = 0$ represents a complete destruction of crop production by the pest at a certain low level of control measure. $G(.)$ is a function of non-decreasing in Z and approaches one as use of damage control agent increases. Assuming a Cobb-Douglas production function for $f(X)$ and the damage abatement function, $G(Z)$, with either an exponential or a logistic specification, then equation (1) can be written as:

$$(2) \qquad Y = a_0 \Pi_i^n X_i^{ai} \,[1 - exp(- c\, Z)], \quad \text{or}$$

$$(3) \qquad Y = b_0 \Pi_i^n X_i b_i \,\{1/[1 + exp\,(d - h\, Z)]\}$$

where a_0, a_i, c in (2) and b_0, b_i, d and h in (3) are parameters to be estimated, i index inputs including labor and various fertilizers (N, P, and K), and Z is farmer's pesticide use. Models (2) and (3) were estimated using nonlinear methods. In order to compare the results from the traditional production approach, a C-D production function was estimated using ordinary least square (OLS), where pesticide use was specified as the same as other inputs such as labor and fertilizers.

Farmers' Pesticide Adoption Model

The models specified above, however, do not account for endogenous problems in pesticide use. Since pesticides are applied in response to pest pressure, and high levels of infestations are correlated to lower crop yields, then a relationship between pesticides and negative residuals in production function might bias parameter estimates for pesticide and other variables. In other words, pesticides adopted by farmers may be endogenous to production. Since there is a systematic relationship among plant diseases, pesticide use, and rice yield, a system model of pesticide adoption and production response should be estimated using a maximum likelihood estimation technique. To empirically account for this endogenous problem, the farmer's pesticide adoption model was estimated first. The predicted values of the pesticide use were then used in the estimation of models (2) and (3).

The farmers' pesticide adoption behavior was hypothesized to depend on the incentive gained from pesticide application (private profitability), farmer's characteristics, and environments where the crop production activities are based. Although no input and output price variations were observed for individual pesticides at a given time, there was a large variation in the mixed average prices of pesticides among households (reflecting the differences in quality and composition used by farmers). Private profitability from pesticide use was measured by farmer's expected yield losses due to pest problems and the mixed average price of pesticides.

Farm and farmer's characteristics could include farmer's education, age, gender, occupation, farm size, etc. Impacts of these variables on farmer's pesticide application might come in two forms. One is their direct impact on farmer's pesticide use and the other is their indirect impact on farmer's perception of yield loss. For example, education and farming experience were both expected to relate to the quality of farmer's judgment and expectations, and therefore the farmer's perception of yield loss. So in specifying the pesticide adoption model, both farmer's perception and farm and farmer's characteristics were included as variables.

Environmental factors that might have impacts on farmer's pesticide adoption could include the sources of pest management information (quality of plant protection extension services), rice cropping seasons, and a set of variables for village dummies that accounted for any other unexplained regional fixed factors.

Based on the above discussion, the farmer's pesticide adoption (*Pesticide*) model can be explained by the following equations:

(4) *Pesticide* = f (Profitability; Farm Characteristics; Extension Service; Others)
= f (*Yloss; Pmix, Education, Age, Sex, RiceArea, LaborCost; ExtService, Season Dummies, Village Dummies*).

where *Yloss* is the farmer's perception of rice yield loss due to pest problems. *Pmix* is the average mixed unit value of pesticide (a proxy for pesticide quality). *Education* is a dummy variable with 1 for farmers with education levels higher than middle school, 0 otherwise. *Sex* equals 1 for male and 0 for female. *Age* is measured in years. *LaborCost* is the opportunity cost of labor and is proxied by per capita income in the regression. *ExtService* is a variable representing the quality of service provided by the local extension system. Since village dummies may take away part of *ExtService* effects on farmer's perception, the sources of pesticide application information may used as a proxy for plant protection extension service. *RiceArea* is average rice area per season. Based on the rice cropping system, rice may be divided into double-season early rice, double-season late rice, single-season middle rice, and single-season late rice. Dummy variables were used to differentiate the variations of pesticide use among various seasons of rice. Among the above variables, *Pmix, Age, Sex, RiceArea, LaborCost,* and *ExtService* were considered as instrumental variables in estimating pesticide use, the latter was used as a right hand side variable in rice production function. The dependent variable, *Pesticide*, was defined in three ways: frequency (times), quantity (kg/ha), and cost (yuan/ha) of pesticide application for each season of rice. The model was estimated using the ordinary least square (OLS) method.

5.4 Estimation Results and Discussion

While the damage control rice production model and pesticide adoption model were estimated simultaneously with the predicted values of pesticide use in the damage control model, their results will be discussed separately.

Pesticide Adoption

Alternative specifications of models showed robust results. All models gave reasonably high R^2 values, ranging from about 0.4 to 0.6, for cross-sectional household data. As expected, farmer's perception of yield loss had the largest positive and statistically significant effects on the level of pesticide applications.

In terms of volume and cost of pesticide use, a 10% decline in farmer's perception of yield loss due to pest (i.e., from current average level of 75.6% to 65.6%) was found to reduce farmer's pesticide use by 2.2% (Model II, Tables 24 and 25). The field experiment on yield loss indicated that yield loss due to pest problems was overestimated by about 35%. Therefore, a significant reduction of farmer's pesticide application could be achieved if farmers were given better information on the real impact of pest problems, which could reduce farmer's attitude toward risk aversion in pest management. Similarly, a 10% decline in farmer's yield loss perception would reduce the number of pesticide application by 2-3 times (from the current 8.0 times to 5-6) for each rice cropping season (Appendix Table 1).

Interestingly, rice area had a significant positive impact on the frequency of pesticide application, but not on volume and cost of pesticide use by the farmer. Doubling farm size would increase pesticide application by 0.67 (Appendix Table 1), but this had no impact on the total pesticide used (Tables 23 and 24). The significant negative coefficients for age in pesticide cost and volume specifications but not in frequency indicated that old farmers applied pesticide in rice production as many times as young farmers but the amount of pesticide use was lower than the latter (Tables 24 and 25).

The average mixed pesticide price (or quality of pesticides) had the expected negative impact on the volume and positive impact on the total cost of pesticides. Improvement in pesticide quality seemed to be very important in reducing the level of pesticide uses. For example, doubling the average mixed pesticide price by having better quality pesticides that were available in the market increased total cost of pesticide use by only 37% (Model II, Table 25), but decreased total pesticide use by 63% (Model II, Table 24).

Significant differences in pesticide use among various rice seasons were also expected. For example, assuming other things are constant, pesticide application in double-season late rice was 9.26 kg (Model I, Table 24), 2.85 kg or 46% (Model II, Table 24) more than that in double-season early rice. Pesticide application in single-season late rice was about 42% more than that in double-season early rice. That pesticide use did not differ significantly between single-season middle rice and double-season late rice was somewhat unexpected. The high correlation between single-season middle rice (almost all in Jiaxing county) and village dummies might have contributed to the insignificance of the single-season middle rice coefficient.

A statistically significant lower pesticide use level in Zhengbei and Yangzhuang, Jiaxing compared with the other villages confirmed the fact that a better plant protection service was provided by the local agricultural technology extension station in Zhengbei and Yangzhuang villages.

Table 24. Estimated parameters for amount of farmers' pesticide application per rice growing season in Zhejiang province.

Variable	Pesticide use (kg/ha)	Ln (kg/ha)
	Model I	Model II
Intercept	43.17 (6.35)***	5.58 (0.71)***
Farmer's perception of yield loss	7.86 (3.71)**	0.22 (0.13)*
Average mixed price of pesticides (AMPP)	-1.04 (0.15)***	
Ln (AMPP)		-0.63 (0.07)***
Information from ATES	3.00 (1.60)*	0.13 (0.06)**
Ln (Rice area)	0.12 (0.21)	
Rice area		-0.05 (0.04)
Income/person	0.0004 (0.0003)	
Ln (Income/person)		0.06 (0.05)
Age	-0.23 (0.09)***	
Ln(Age)		-0.41 (0.13)***
Dummies: Double-season later rice	9.26 (1.96)***	0.46 (0.07)***
Single-season middle rice	-0.92 (3.27)	0.17 (0.12)
Single-season late rice	8.86 (1.98)***	0.42 (0.04)***
Higher than middle school	1.59 (2.51)	0.08 (0.09)
Male	0.19 (2.23)*	-0.02 (0.08)
Village dummies: Zhengbei	-17.13 (3.10)***	-0.65 (0.11)***
Yangzhuang	-9.92 (3.05)***	-0.30 (0.11)***
Yushanwu	0.20 (2.78)***	-0.03 (0.10)
R^2	0.41	0.48
Adjusted R^2	0.37	0.44

Note: The figures in parentheses are standard errors of estimates. ***, **, * denote significance at 1%, 5%, and 10%, respectively.

Table 25. Estimated parameters for pesticide cost of per hectare rice production in Zhejiang province.

Variables	Pesticide cost (yuan/ha)	Ln (yuan/ha)
	Model I	Model II
Intercept	279.26 (71.38)***	5.58 (0.71)***
Farmer's perception on yield loss	58.92 (41.67)	0.22 (0.13)*
Average mixed price of pesticides (AMPP)	5.79 (1.65)***	
Ln (AMPP)		0.37 (0.07)***
Information from ATES	30.00 (17.94)*	0.13 (0.06)**
Ln (Rice area)		-0.05 (0.05)
Rice area	2.08 (2.39)	
Income/person	0.0015 (0.004)	
Ln (income/person)		0.06 (0.05)
Age	-1.66 (0.97)*	
Ln(Age)		-0.41 (0.13)***
Dummies: Double-season late rice	103.51 (22.09)***	0.46 (0.07)***
Single-season middle rice	-4.81 (36.75)	0.17 (0.12)
Single-season late rice	97.68 (22.31)***	0.42 (0.07)***
Higher than middle school	29.37 (28.21)	0.08 (0.09)
Male	-35.06 (25.10)	-0.02 (0.08)
Village dummies: Zhengbei	-182.12 (34.88)***	-0.65 (0.11)***
Yangzhuang	-95.76 (34.26)***	-0.30 (0.11)***
Yushanwu	31.91 (31.25)	-0.03 (0.10)
R^2	0.49	0.59
Adjusted R^2	0.45	0.56

Note: The figures in parentheses are standard errors of estimates. ***, **, and * denote significance at 1%, 5%, and 10%, respectively.

Impacts on Rice Production

Given the robust estimates of pesticide adoption models presented in the last sub-section, the predicted value of pesticide adoption from Model II of Table 25 was used as an explanatory variable in the rice yield equation because the model had the highest R^2 value among all estimated adoption models. Non-linear estimates of damage control rice production functions with the endogenous pesticide use are summarized in Table 26.

With no change in other inputs and no location impacts, a higher yield for both single-season middle and late rice (compared with double-reason early and late rice) was expected. The yield of single-season middle rice was about 12-14% higher than the yields of both double-season early and late rice, while the yield of single-season late rice was about 8-10% higher than the yields of double-season rice. The results were very similar in the three models estimated (Table 26).

After controlling for the yield differences due to rice growing season, a significant positive coefficient of Zhengbei reflected a better infrastructure development and a better local extension system in the village compared with the other three villages.

Similar to the findings of early studies on very low elasticity values of both labor and fertilizer in rice production (Huang et. al, 1994 and 1995; Widawsky et.al., 1998), the estimated labor elasticity was about 0.07 and the marginal contribution of fertilizer in the sample farms approached zero. The low labor elasticity in rice production was consistent with the observation of large labor surplus in rural China. Farmers in the sample areas applied 282 kg/ha fertilizer at effective nutrition base, a level already considered as one of the highest in the world. Therefore, the insignificant marginal contribution of fertilizer to rice production was expected.

Table 26 also shows that rice yield could be significantly improved if the share of potash fertilizer will be increased. Given the same amount of fertilizer but raising the proportion of potash fertilizer by 10%, rice yield would increase by 1.7%. This result confirmed early findings by Huang et al. (1994 and 1995).

Among three alternative models, only the production function with exponential damage control specification showed a statistically significant impact of pesticide use on rice production (Table 26). The statistically insignificant impacts of pesticide variables in the C-D model and in the model with logistic damage control specification suggest that the marginal contribution of pesticide use at current level to rice production was zero, which could be one possible indicator of overuse of pesticide by farmers in rice production. This result confirmed the results of Widawsky et al. (1998) which found that elasticity and marginal value of pesticide were either zero or insignificantly negative.

Table 26. Estimated parameters for rice yield (ton/ha).

	C-D function	Ln (yield) with damage control function	
	Ln (yield)	Exponential	Logistc
Variables	Model I	Model II	Model III
Intercept	1.00 (0.37)***	1.35 (0.21)***	1.38 (0.21)***
Ln(labor)	0.07 (0.03)**	0.07 (0.03)**	0.07 (0.03)**
Ln(Fertilizer)	-0.002 (0.03)	-0.002 (0.03)	-0.003 (0.03)
Ratio of phosphate fertilizer	0.10 (0.15)	0.09 (0.15)	0.10 (0.15)
Ratio of potash fertilizer	0.16 (0.07)***	0.17 (0.07)**	0.17 (0.07)**
Dummies: Double-season late rice	0.01 (0.04)	0.02 (0.04)	0.001 (0.05)
Single-season middle rice	0.14 (0.05)***	0.13 (0.05)**	0.12 (0.06)**
Single-season late rice	0.09 (0.04)**	0.10 (0.04)**	0.08 (0.04)*
Higher than middle school	-0.02 (0.04)	-0.02 (0.04)	-0.02 (0.04)
Village dummies: Zhengbei	0.14 (0.06)**	0.12 (0.05)**	0.14 (0.07)**
Yangzhuang	0.08 (0.05)*	0.07 (0.05)	0.07 (0.05)
Yushanwu	-0.05 (0.04)	-0.04 (0.04)	-0.04 (0.04)
Ln(Predicted pesticide)	0.06 (0.06)		
c (in exponential model)		0.03 (0.01)**	
d (in logical model)			-1.13 (1.56)
h (in logical model)			0.01 (0.01)
R^2	0.19	0.19	0.19
Adjusted R^2	0.14	0.13	0.13

Note: The figures in parentheses are standard errors of estimates. ***, **, * denote significance at 1%, 5%, and 10%, respectively.

Because only the pesticide parameter in exponential damage control specification was found to be statistically significant from zero, the succeeding discussion will be based on the parameter implied by *C* in Table 26 (0.03). Using this parameter and mean values of rice yield and all right-hand side variables as bases, the elasticity, average product, and marginal product of pesticide use in rice production at mean level were computed. On the average, the farmers applied 287 kg/ha pesticides. The average rice production was 22 kg/kg of pesticide use (Table 27). Pesticides did significantly contribute to rice production through yield loss abatement when used at an average level. However, at high levels of pesticide use, rice output elasticity of pesticide use was close to zero and marginal product of pesticide declined to 0.02 kg for single-season late rice and 1.46 kg for double-season early rice. For all seasons, the marginal product of pesticide was only 0.07 kg.

Table 27. Pesticide productivity in rice production based on the exponential damage control model.

	Average	Double-season early rice	Double-season late rice	Single-season middle rice	Single-season late rice
Pesticide use (yuan/ha)	287	175	289	325	342
Y (ton/ha)	6.4	6.0	6.4	6.5	6.7
Average product (kg rice for every yuan of pesticide use)	22	34	22	20	20
Elasticity	0.0033	0.0430	0.0030	0.0013	0.0008
Marginal product (kg rice for additional yuan of pesticide use)	0.07	1.46	0.07	0.03	0.02
Optimal pesticide use (kg/ha)	201	190	200	200	202
Ratio of actual/optimal use of pesticides	1.43	0.92	1.45	1.63	1.69

Figure 1 shows the trend of rice marginal product values with respect to pesticide cost evaluated at means of all non-pesticide variables. The marginal rice production values declined significantly with increases in pesticide uses. The increases in rice output approached zero as pesticide use level increased to a level above 200 yuan/ha. Based on the trend, the optimal pesticide use level was 201 yuan/ha evaluated at the mean value of rice price (Table 27). This was substantially lower than the actual expenditure on pesticide use. Pesticide use by the farmers in the sample areas was 42% higher than the optimal level (287/201 = 1.43).

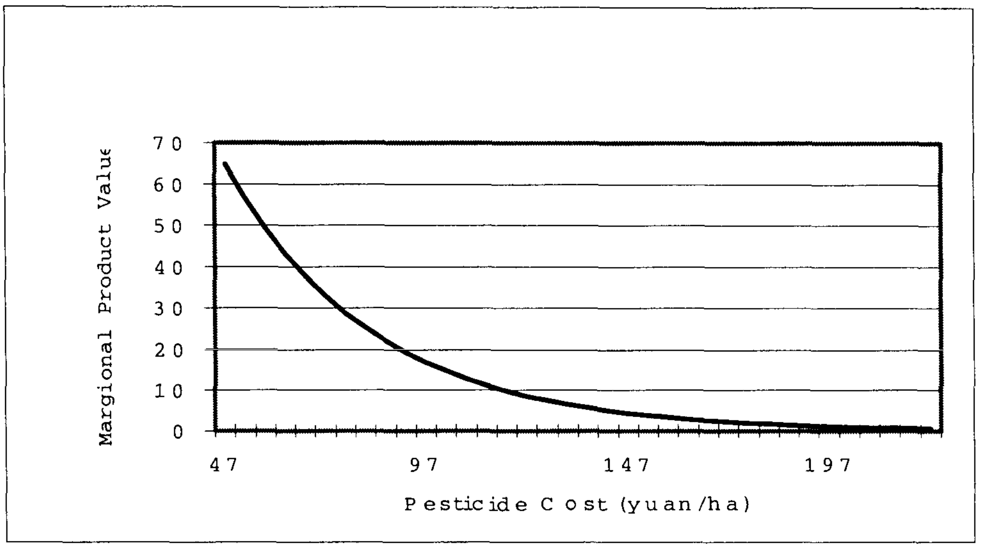

Figure 1. Marginal product value of pesticide use in rice production

Among the various rice seasons, pesticide overuse was most severe in single-season late rice (69%), followed by single-season middle rice (63%) and double-season late rice (45%). Unexpectedly, current pesticide use in double-season early rice was still 8% below the optimal level. This might be due to the damage control function that applies the same parameter of *C* in the exponential specification to all rice seasons. On the other hand, the parameter *C* estimated from the average of 4 different rice seasons might be under valued for double-season early rice, resulting in an over estimation of the marginal rice production value of pesticide use. Effort was made to add a dummy variable for double-season rice in the exponential damage control function, however, this was not successful because the non-linear model failed to converge.

The above analyses showed that while pesticides contributed significantly to rice production by limiting yield losses, the marginal contributions of pesticide use declined considerably with increase in pesticide use, and approached zero at current average pesticide use level by the rice farmers. Pesticide overuse by the farmers was substantial. Among the various factors that determined farmers' decision on pesticide use, the most important were: farmer's own perception of yield loss due to pest diseases, quality of pesticides, local agricultural and extension services, and specific crop protection service. Therefore, the level of farmer's pesticide application could be significantly reduced by providing farmers better information on the real impacts of pest diseases, improving in the quality of pesticides, and strengthening the local agricultural extension system.

6.0 IMPACTS OF PESTICIDE USE ON FARMERS' HEALTH

Pesticide poisoning affected from 53,300 to more than 123,000 persons each year in China in the past decade (Huang, et al., 2000). About half of the poisoning cases were related to pesticide use in crop production[8]. On the average, China had about 10,000 deaths due to pesticide poisoning every year, though the number had declined significantly since the late 1980s and reduced to less than 4,000 in 1996. There were about 300-500 deaths due to improper and over use of pesticide in crop production in normal years (Huang, et al., 2000).

The effects of the pesticides on human health include not only acute diseases but also chronic diseases in both production and non-production related activities. China classifies pesticides into four categories based on their relative acute hazard levels. No formal classification though is available for chronic hazards. Most of the new chemical pesticides belong to category III and IV, which are commonly regarded as having less threat to humans. But recently, scientists found that pesticides under categories III and IV could cause critical chronic diseases that are not easy to observe visually. Hence, pesticides under categories III and IV should be paid as much attention as categories I and II pesticides.

6.1 Evidence from Rice Farmers

To determine the effects of pesticide use on farmers' health, the farmers were examined by a medical team of two physicians and two nurses. The examinations included obtaining general information on the farmers' physical and medical situation, observing for acute poisoning symptoms, as well as conducting biochemistry, blood, and pathology tests.

The farmer's health measures derived from the above health examinations related to pesticide use included both visible and invisible indicators. The visible indicators are those that can be directly obtained by interviewing farmers. The invisible indicators are those that accumulate in the human body and are reflected by the functions of the liver, kidneys, neurological and other systems. The visible health impairment measures are often used by researchers as evidence of the effects of pesticide use on farmers' health, but measurement errors could lead to a wide range of conclusions and even inconsistent results. Farmers' response to interviewers are highly influenced by his/her own perception of what should be considered as health impairment or illness even if the interviewer has given the farmer a clear definition of the impairments. Consistent results can be found only in health incidents where farmers are

[8] The other half was due to purposive use of pesticides (e.g., suicide) or careless/handling/use of pesticides.

seriously poisoned by pesticide or they have to rest (i.e., have a day off) for health recovery. In view of this, the visible health impairment data analyzed in this study dealt only with those cases with "seriously poisoned" observations. Therefore, the effects of pesticide use on farmer's health using the visible health presented here may be underestimated, but they are consistent among farmers.

Eye effects. Many farmers reported that they felt some discomfort in their eyes when they applied pesticides, however, few of them considered the discomfort as severe. Among 100 farmers interviewed, only 3 farmers considered the effect of pesticide use on their eyes as severe. But no one considered the effect serious enough to need medical treatment or take time off from work. An examination of the farmers' pupils showed that the pupils ranged from 0.20 cm to 0.30 cm., and all were within normal range. While the study did not find significant eye effects of pesticide, other studies showed the ill-effects to include decreasing eyesight, eye pain, among others (Li, 1998; Peng, 1998).

Headache. Among 100 farmers interviewed, seven farmers reported having experienced serious headache when they applied pesticides during the last rice growing season. However, the farmers often experienced slight headache (i.e., feeling somewhat dizzy but did not required rest) when they applied pesticides for more than 2-3 hours (Table 28).

Skin effects. Skin, the main door for pesticides to enter human body, can be seriously harmed by pesticides. Ten percent of the farmers reported having skin pain when they applied pesticides (Table 28). Most of the farmers felt a tickling sensation especially when the pesticide spilled on their skins.

Respiratory tract effects. When farmers apply pesticides, some pesticide particles floating in the air can enter the human body through the respiratory tract. Cough was often observed in the sample farmers, but only 3% of farmers experienced nausea or decreasing chest expansion when they applied the pesticides (Table 28).

Table 28. Number of poisoning cases as reported by 100 farmers in 1998.

Symptom	Total	Jiaxing	Anji
Headache	7	5	2
Nausea	3	1	2
Skin pain	10	2	8
Multiple symptoms	20	8	12

Note: The figures are the number of farmers with the indicated symptoms. The total sample was 100, with 25 farmers from each village, 2 villages from each county. The surveys were conducted in Jiaxing and Anji counties, Zhejiang province.

Having only a few samples and the difficulties in measuring the effects of pesticide use on farmer's health lead the researchers to focus their analysis more on the results of the farmers' laboratory tests[9]. The health indicators have been developed to measure possible effects (particular chronic effect) of pesticide on human health and are provided in Huang, et al. (2000). They include indicators for the blood system and functions of the liver, kidneys, neurological system, and others. A summary of major indicators is presented in Table 29.

Table 29. Summary of results of laboratory tests for 100 farmers in Zhejiang province.

	Normal Range	Abnormal cases		
		Total	Less than lower boundary	Greater than upper boundary
Blood effects				
Hgb	110-160	8	8	0
PLT	100-300	69	69	0
Liver effects				
ALT	0-40	22	0	22
AST	0-40	14	0	14
Kidney effects				
BUN	3-7.2	23	1	22
UA	150-430	4	1	3
Neurological effects				
CHE	30-80 (4500-13000)	5	5	0

Note: Hgb-Hemoglobin; PLT-platelet; ALT-alanine transaminase; AST-aspartic transaminase; UA-uric acid; BUN-Urea nitrogen; CHE-choline esterase.

Cardiovascular effects. Acute pesticide poisoning is mainly caused by the pesticide entering the blood. As soon as the pesticide enters the body, it enters the blood system, which makes it difficult to observe its effects by a simple dialogue check. The blood test results in Table 29 showed abnormalities in the blood platelets and white blood cells of many farmers. However, further analysis by stratifying results based on pesticide use did not lead to a significant difference in these statistics among different pesticide use groups.

Liver function. Pesticides can enter the gastrointestinal tract accidentally through the mouth. When ingested, carbamate insecticides formulated in methyl alcohol may cause severe gastroenteritic irritation (Morgan, 1977).

[9] This study benefited greatly from several meetings in Beijing and Nanjing, where medical doctors from hospitals provided very useful comments on pesticide related health problems and health indicators for both general and laboratory tests.

Organophosphates and copper salts irritate the gastrointestinal tract, resulting in intense nausea, vomiting, and diarrhea. Alanine transaminase (ALT) and aspartic (AST) are two important indicators of the liver's function. Many factors affect ALT and AST, of which pesticide is one of them. When a person is exposed to pesticide, his/her ALT and AST values will rise with the level of pesticide exposure. In 100 farmers examined, 22 farmers had ALT values higher than the normal range, while 14 farmers had AST values exceeding the normal range for the common population (Table 30). Stratifying the ALT and AST by pesticide use indicated that there was a close linkage between the abnormality of ALT and AST and level of pesticide application of farmers.

Kidney effects. Kidney helps to ensure the efficient functioning of body cells through a number of mechanisms: regulation of extra-cellular fluid volume, control of electrolytes and acid-base balance; excretion of toxic and waste products, and conservation of essential substances. High exposure to circulation toxins and long-term exposure to organophosphate compounds could lead to renal tubular abnormalities. Nephrotoxic agents such as endrin and endosulfan can also cause kidney abnormalities. Cases of pesticides affecting the kidney function had been reported by many researchers (Lei, et al. 1998). Among the 100 rice farmers in the sample, 23 farmers had abnormal levels of blood urea nitrogen (BUN), 22 of which had BUN values exceeding the upper boundary for the normal population (Table 29).

Neurological effects. Most pesticides are neurotoxicants. Choline esterase (CHE) is a major indicator in monitoring the neurological effects of pesticide use. When pesticides enter the human body, they mix with the protein enzyme and affect its function. When this happens, the value of CHE will decrease. In the survey sample, 6% of the farmers had CHE values less than the lower limit of the range for a normal population (Table 29).

6.2 Health Costs of Pesticide Use in Rice Production

Health costs related to pesticide use are commonly computed based on the treatment required to restore the farmer's health. They include the expenses for medication, physical examination fee, and the opportunity costs of farmers' lost time due to recuperation. Because of the difficulty in estimating the costs related to the treatment required to restore farmers' health to its normal state, the health costs discussed in this chapter are limited to the treatments related to visible health impairments.

Table 30 summarizes farmer's health costs stratified by pesticide use levels. The results clearly indicated a strong linkage between farmer's health costs and pesticide use. On the average, each rice farm applied 14.07 kg of pesticide. The health cost related to this level of pesticide application was 21.68 yuan. However, health costs largely varied among farmers. For farmers with pesticide use level greater than 15 kg, their health costs were nearly 3 times as much as those of farmers whose pesticide use was less than 9 kg (33.09 yuan vs 8.59 yuan, Table 30). A similar relationship was observed for the health costs stratified by farm pesticide cost (Table 30).

Health costs may be also linked with farmer's health or physical condition such as age, gender, and smoking/drinking habit, and various pesticides used. In order to arrive at a firm conclusion on the causal relation between farmer's health cost and pesticide use, a control treatment on effects of the above factors would be required.

Table 30. Pesticide use and health cost in the sample households.

		Pesticide application (kg or yuan)		Health cost (yuan)	
	Sample	Mean	Std error	Mean	Std error
Per farm pesticide use	100	14.07	13.46	21.68	55.75
Low than 9 kg	34	6.07	2.27	8.59	26.60
Between 9-15 kg	33	11.76	1.80	23.76	52.31
High than 15 kg	33	24.62	19.06	33.09	76.34
Per farm pesticide cost	100	144.3	137.9	21.7	55.8
Low than 100 yuan	36	73.8	23.6	10.9	29.4
Between 100-150 yuan	35	120.9	17.6	21.1	50.9
High than 150 yuan	29	260.0	212.7	35.7	80.0

Note: The figures in the table were from 100 households in 4 villages of Jiaxing and Anji counties in Zhejiang.

Table 31 shows the basic statistics of the 100 farmers examined and pesticide use by category. Males were the major pesticide users, accounting for 90% of the sample size. More than half of the farmers smoked and 69% drank alcoholic beverages. Most pesticides used by farmers in rice production belonged to categories III and IV. These pesticides are expected to cause more chronic diseases. Of the 14.07 kg of pesticides used by rice farmers per year, 11.59 kg belonged to categories III and IV. This accounted for 82% of total pesticides used by farmers in rice production (Table 31).

Table 31. Pesticide use and statistics on farmers subjected to health examination.

	Mean	Std error
Age (years)	45.4	9.10
No. of males (%)	90	30
Smoking history (years)	11.1	12.1
No. of smokers (%)	51	50
Amount of pure alcohol consumption (kg/day)	0.03	0.03
No. of drinkers (%)	69	46
Pesticide use – kg/year:		
Category I &II	2.47	3.41
Category III&IV	11.59	10.87
Total (I+II+III+IV)	14.07	13.46
Pesticide use – yuan/year:		
Category I &II	28.18	33.10
Category III&IV	116.09	113.05
Total (I+II+III+IV)	144.27	137.94
No.of pesticide applications (times/year)	15.93	6.06

Note: The figures in the table were from 100 farmers in 4 villages of Jiaxing and Anji counties in Zhejiang.

6.3 Models of Health Impairments and Costs

The hypothesized impacts of farmers' pesticide use on their health and costs related to health impairments were examined using health risk models and health cost models, respectively. A health risk model can be specified in a general functional form as follows:

$$(5) \quad Hrisk_i = f(F_i, P_i, Z_i, e_i)$$

where, *Hrisk* denotes health indicator and is equal to 1 if the health effect occurred or the health indicator is not in the range of normal cases; it is equal to 0 otherwise. Indicators for the health impairments were headache, nausea and skin pains for visible health impairments and abnormal laboratory test results for the liver, kidney, and neurological functions for invisible health impairments. *F* is a vector of farmers' characteristics expected to have impacts on the probability of farmers having the health impairments investigated. These included sex, height, weight, smoking/drinking habit. *P* is pesticide used by farmers. *Z* is regional fixed factors such as local quality of drinking water and environments. The *i*'s denote farmers. The small number of cases of health impairments for each individual illness disabled the study from running the model separately for each impairment. Instead, the study constructed *Hrisk* as equal to 1 if any health impairment was present, and 0 otherwise.

In the empirical estimation, the health impairment model is specified as follows:

$$(6) \quad Hrisk_i = a_0 + a_1{*}Dmale_i + a_2{*}\,Ln(Age_i) + a_3{*}\,Ln(Smoke_i) + a_4{*}\,Ln(Drink_i) + a_5{*}\,Weight_i/height_i + a_6{*}\,Pesticide_i + a_7{*}\,Dregion_i + e_i$$

Variables with continuous values such as *Age*, *Smoke* (amount/day), and *Drink* (kg/day) were specified in natural log form. For those with zero value for *Smoke* and *Drink*, a small value (0.0001) was assigned. Pesticide was specified in several forms as alternative specifications to the models: total use (in volume or cost), by categories of pesticides, frequency of applications (time). Volume and cost were used as alternative specifications since the cost reflected more the "quality" of pesticides used by the farmers. This was evident in the surveys which showed that while the individual pesticide prices were the same (for a cross section data in a given time period), the average price of all pesticides purchased by farmers differed substantially. *Weight* was also specified as two alternatives: weight and weight/height. *Dmale* is a dummy variable and is equal to 1 for male and 0 for female. Since the dependent variable in this equation was a discrete variable, ordinary least squares may produce biased and inconsistent parameters estimates (Maddala, 1983). Therefore a probit model was used to estimate the parameters.

A health cost was specified similarly as in the health impairment model except for the dependent variable. The estimated health cost model is as follows:

$$(7) \quad Ln(Hcost)_i = b_0 + b_1{*}Dmale_i + b_2{*}\,Ln(Age_i) + b_3{*}\,Ln(Smoke_i) + b_4{*}\,Ln(Drink_i) + b_5{*}\,Weight_i/height_i + b_6{*}\,Pesticide_i + b_7{*}\,Dregion_i + e_i$$

where, *Ln(Hcost)* denotes health cost in natural log form. For those with zero cost of health related to pesticide use, the observation was replaced by a small value (both 1 yuan and 0.0001 yuan were tried; the results were robust to the alternative specified small values). Model (7) was estimated by OLS method.

6.4 Estimated Results of Health Impairment and Cost Models

Health Impairment Model

The estimates of the health impairment models for equation (6) are presented in Tables 32 and 33 and Appendix Table 2. As Table 32 shows, pesticide use significantly affected farmers' health impairments. The statistically significant and positive coefficient for categories III and IV pesticides indicated that the incidence of farmers' health impairments (headache, nausea, and skin illness) rises with the increase in pesticide use. The same result was obtained when pesticide specifications were given in either volume or value.

The insignificant coefficient for categories I and II pesticides might be due to the small amount of this category of pesticides used by the farmers. Indeed, pesticide use was one of two factors that had significant impacts on farmers' health impairments. It is interesting to note the significant negative coefficient for age, which was consistent with the researchers' observations during the field survey. That is, the older the farmer, the more experience in pesticide use.

Table 32. Estimates of health impairments (headache, nausea, and skin illness) of rice farmers in the sample villages of Zhejiang province.

	Model I	Model II
Intercept	4.97 (6.32)	1.77 (6.09)
Respondents' characteristics:		
Male dummy	1.27 (1.07)	1.37 (1.05)
Ln(Age)	-2.83 (1.45)**	-2.95 (1.44)**
Ln(Smoke)	0.02 (0.05)	0.02 (0.05)
Ln(Drink)	0.04 (0.07)	0.05 (0.07)
Weight/height	7.60 (5.86)	7.80 (5.77)
Chemical use – kg/year:		
Ln (Categories I&II)	-0.02 (0.09)	
Ln (Categories III&IV)	1.21 (0.53)**	
Chemical cost – yuan/year:		
Ln (Categories I &II)		0.02 (0.07)
Ln (Categories III&IV)		0.95 (0.50)**
Ln (Number of applications)	-0.86 (1.16)	-0.15 (1.06)
County dummy: Jiaxing	-0.63 (0.79)	-0.74 (0.80)
Chi2(9)	16.68	14.69

Note: The figures in parentheses are standard errors of estimates. ***, **, and * denote significance at 1%, 5%, and 10%, respectively.

A surprising result was that none of the farmer's characteristics, except for age, had a significant effect on farmers' health impairments (e.g., headache, nausea, and skin illness) (Table 32).

Using BUN, ALT and CHE as indicators for the functions of the liver, kidney, and neurological system, respectively, the estimates of multiple abnormality models of farmer health (Table 33) revealed that categories III and IV pesticides had significant impacts on farmers' health condition. This result confirmed previous findings on the impact of categories III and IV pesticides on chronic diseases of the liver and kidney.

The regression results (Table 33) also showed that incidence of health abnormality was higher among male farmers than females. The significant positive sign for the ratio of weight to height was contrary to expectations. The positive sign implies that the heavier the weight, the higher the probability of health to be abnormal after controlling for height effect of the individuals.

Table 33. Estimates of multiple abnormalities (BUN, ALT, and CHE) in rice farmers in the sample villages of Zhejiang province.

	Multiple abnormality in rice farmers	
	Model I	Model II
Intercept	6.35 (4.87)	5.39 (4.82)
Respondents' characteristics:		
Male dummy	-0.69 (0.26)***	-0.68 (0.26)***
Ln (Age)	-0.20 (0.27)	-0.19 (0.27)
Ln (Smoke)	0.003 (0.009)	0.003 (0.010)
Ln (Drink)	-0.02 (0.01)*	-0.02 (0.01)*
Ln (Weight)	-1.89 (1.49)	-1.76 (1.48)
Weight/height	7.94 (4.64)*	7.48 (4.61)*
Ln(Chemical use – kg/year)		
Ln (Categories I&II)	-0.003 (0.02)	
Ln (Categories III&IV)	0.15 (0.09)*	
Ln(Chemical cost – yuan/year)		
Ln (Categories I&II)		-0.002 (0.016)
Ln (Categories III&IV)		0.17 (0.10)*
Ln (Number of applications)	-0.16 (0.23)	-0.12 (0.22)
Anji county dummy	0.08 (0.15)	0.06 (0.15)
$Chi^2(10)$	16.72	16.98

Note: The figures in parentheses are standard errors of estimates. ***, **, and * denote significance at 1%, 5%, and 10%, respectively.

More observations on BUN abnormality enabled the researchers to run a separate model on the impact of pesticide use on kidney function. The results (Appendix Table 2) confirmed the expectations that categories III and IV pesticides have significant impacts on farmers' kidney function.

Health Cost Model

The estimated parameters for farmers' health cost models are presented in Tables 34 and 35. While the coefficients for pesticide use and location fixed effect (i.e., varying the quality of drinking water and living environment) factors were significant and consistent with expectations, none of the respondents' characteristics had statistically significant effects on farmers' health cost. This was unexpected because some of these variables were found to significantly affect rice farmer's health costs in similar studies done in the Philippines and Vietnam (Rola and Pingali, 1993; Dung and Dung, 1999).

Table 34. Estimates of health cost of rice farmers in the sample villages of Zhejiang province (based on volume of pesticide use).

ITEM	Ln (health cost)			
	Model I	Model II	Model III	Model IV
Intercept	4.02 (4.13)	2.92 (4.11)	4.48 (4.03)	3.19 (4.10)
Respondents' characteristics:				
Male dummy	0.94 (0.68)	1.01 (0.68)	0.87 (0.68)	0.98 (0.69)
Ln (Age)	-1.13 (0.90)	-0.85 (0.91)	-1.28 (0.89)	-1.12 (0.91)
Ln (Smoke)	0.02 (0.03)	0.02 (0.03)	0.02 (0.03)	0.02 (0.03)
Ln (Drink)	0.03 (0.04)	0.03 (0.04)	0.03 (0.04)	0.04 (0.04)
Weight/height	5.59 (3.64)	5.23 (3.57)	5.14 (3.71)	5.28 (3.71)
Ln (Chemical use: kg/year):				
Ln (Categories I&II)	0.06 (0.06)		0.04 (0.06)	
Ln (Categories III&IV)	0.54 (0.30)*		0.87 (0.29)***	
Ln (I+II+III+IV)		0.03 (0.01)*		0.03 (0.01)**
Ln (Number of applications)	-0.72 (0.74)	-0.34 (0.66)	-0.28 (0.65)	-0.46 (0.51)
Village dummies:				
Zhengbei	-1.17 (0.57)**	-1.27 (0.55)**		
Yangzhuang	-0.91 (0.59)	-1.12 (0.57)*		
Yushanwu	-1.34 (0.54)**	-1.57 (0.51)***		
R^2	0.24	0.23	0.18	0.13
Adjusted-R^2	0.15	0.15	0.10	0.06

Note: The figures in parentheses are standard errors of estimates. ***, **, and * denote significance at 1%, 5%, and 10%, respectively.

The insignificant coefficients of the farmers' specific characteristics in the model might be due to the different coverage of health costs. In the study, only the costs of health impairments that are severe and require time for the patient to recover or take rest were included. Although slight health impairments such as headache and those related to the eyes, skin and others were also recorded, the medical team strongly rejected the inclusion of these observations and estimation of "explicit" health costs for the following two reasons: 1) inconsistent measurement among the respondents even if the interviews were conducted by the medical team, 2) difficulty in estimating the health costs of small, short-duration health impairments.

On the other hand, the significant impact of pesticide use on farmer's health cost was consistent with previous studies in other countries. The results did not vary with pesticide use specifications (i.e., volume or value). Holding constant the total amount of pesticide use, Model III (Table 35) showed that the more frequent the pesticide use (and therefore the smaller amount of pesticide applied each time), the lesser the health costs.

Based on the parameters presented in Tables 34 and 35, the farmers' health costs from pesticide use was computed at the average and marginal levels. The sample mean values for all variables were used in the computation. The results are summarized in Table 36.

At the current level of pesticide use, Table 36 shows that the average health cost per yuan of categories III and IV pesticides use was 0.19 yuan (1^{st} column) or 0.17 yuan (3^{rd} column). The marginal health cost value indicated that each additional yuan of categories III and IV pesticide use will cause the health cost to increase by 0.12 yuan (1^{st} column) or 0.09 yuan (3^{rd} column).

Table 35. Estimates of health cost of rice farmers in the sample villages of Zhejiang province (based on pesticide cost).

	Ln (health cost)			
	Model I	Model II	Model III	Model IV
Intercept	1.86 (4.10)	2.88 (4.12)	1.48 (4.08)	3.13 (4.12)
Respondents' characteristics:				
Male dummy	1.02 (0.67)	0.99 (0.68)	0.96 (0.69)	0.94 (0.70)
Ln (Age)	-1.07 (0.90)	-0.85 (0.91)	-1.34 (0.90)	-1.16 (0.92)
Ln (Smoke)	0.02 (0.03)	0.02 (0.03)	0.02 (0.03)	0.02 (0.03)
Ln (Drink)	0.04 (0.04)	0.04 (0.04)	0.05 (0.04)	0.04 (0.04)
Weight/height	5.39 (3.65)	5.05 (3.57)	5.04 (3.76)	5.09 (3.73)
Chemical cost – yuan:				
Ln (Categories I &II)	0.07 (0.05)		0.06 (0.05)	
Ln (Categories III&IV)	0.65 (0.31)**		0.85 (0.31)***	
Ln (I+II+III+IV)		0.002 (0.001)*		0.003 (0.001)*
Ln(Number of applications)	-0.71 (0.69)	-0.28 (0.65)	-1.18 (0.59)**	-0.30 (0.49)
Village dummies:				
Zhengbei	-1.12 (0.56)**	-1.27 (0.56)**		
Yangzhuang	-1.00 (0.57)*	-1.14 (0.57)**		
Yushanwu	-1.54 (0.50)***	-1.64 (0.51)***		
R^2	0.26	0.23	0.17	0.12
Adjusted- R^2	0.17	0.14	0.10	0.05

Note: The figures in parentheses are standard errors of estimates. ***, **, and * denote significance at 1%, 5%, and 10%, respectively.

Table 36. Health cost of pesticide use in rice production.

	Model I in Table 36 (pesticide use in yuan)	Model I in Table 35	
		Original number in model is kg	Conversed kg to yuan
Pesticide I+II			
-- Pesticide use level	28.2	2.5	26.9
-- Average health cost per pesticide use (yuan/yuan or kg)	0.77	8.76	0.80
-- Marginal health cost (yuan / additional unit of pesticide use)	0.05	0.53	0.05
-- Elasticity	0.07	0.06	
Pesticide I+II			
-- Pesticide use level	116.1	11.6	126.3
-- Average health cost per pesticide use (yuan/yuan or kg)	0.19	1.87	0.17
-- Marginal health cost (yuan / additional unit of pesticide use)	0.12	1.01	0.09
-- Elasticity	0.65	0.54	

Note: The sample mean value for health cost per farmer was 21.7 yuan and pesticide price was 10.89 yuan/kg. The figures for pesticide I+II were based on statistically insignificant coefficient of pesticide (I+II) use in the health model. They are presented here for reference only.

7.0 CONCLUSIONS AND POLICY IMPLICATIONS

Intensive cultivation and broad adoption of fertilizer responsive varieties have resulted in widespread pest infestation. The extent of pest-related diseases has grown several times in the past two decades in China. Rising pest problems and availability of pesticides due to market development have increased the use of pesticides in crop pest management. China is soon likely to become the largest pesticide consumer in the world. Pesticide use in grain production has more than tripled within 20 years. Among grains, rice uses pesticides the most intensively.

Given the prospects of China's food situation in the coming century and the central goal of China's food security policy, intensive cropping system with increasing use of modern input will likely continue to be the dominant farming practice in China. An increasing use of farm pesticides is also expected to be continued if no practical alternative pest management technologies, regulations, and policies are developed to effectively reduce the overuse of pesticides in crop production.

The productivity analyses of pesticide use in rice farming based on this study's primary farm level data indicated that the average return to pesticide use was high. Rice yield loss due to pest-related diseases could reach as high as 40% if no pest control is adopted. On the other hand, this study showed that while pesticides contributed significantly to rice production by limiting yield losses, the marginal contributions of pesticide use declined considerably with increased use of pesticides and approached zero at current average pesticide use level by the rice farmers. Given the current rice and pesticide prices, the average overuse of pesticides by farmers was more than 40%, with the highest value of about 70% obtained in single-season late rice.

In the battle against pests, pesticide is a double-edged sword as it also affects human health and contaminates the environment. This study showed that both visible acute health impairments and invisible chronic health diseases (related to the liver, kidney, and neurological system) of rice farmers were closely linked with the extent of their exposure to pesticides. Although the health costs examined in this study were limited to treatments related to a few visible acute health impairments (which could be just a small part of the total health cost), they still accounted for about 15% of pesticide costs. The estimates of multiple abnormality (liver, kidney, and neurological system) models of farmers' health revealed that pesticides have significant impacts on farmer's health condition and could cause chronic diseases of the liver and kidney. If costs related to these chronic disease and other costs not computed in this study such as slight effects of acute diseases (i.e., did not require medical treatment or needed a short recovery period only) and other external costs (e.g., consumer health and environmental costs) were included, the total health cost may be greater than the private cost of purchasing pesticides. In other words, while the overuse of pesticides by farm reached 40%, the optimal use level of pesticide in rice production could be less than half of the current level of pesticide used by farmers if external costs were accounted.

Overuse of pesticides in pest management has been well documented in the literature. However, there is little knowledge on the determinants of pesticide overuse. This study showed that among the various factors that determine farmers' decision on pesticide use, farmer's own perception of the yield loss due to pest problems, quality of pesticides available in the market, local agricultural and extension services (particular plant protection service), and opportunity cost of farm labor were the most important. Therefore, in seeking for a better solution to pest management problems and externalities, the priority issues are not just how to set up regulations and policies that would ban all pesticide use in crop production, but how to use pesticides properly, avoid its overuse, and improve the conditions so that farmers could internalize the externalities (external cost) of pesticide use, and find better alternative pest management practices.

Convincing farmers that their perceptions of crop yield loss due to pest-related diseases are over-estimated and improving farmers' knowledge of pest management and pesticide safety issues are critical. Our analyses showed that farmers had very minimal knowledge of pest management as well as the consequences of pesticide uses. Because of their limited knowledge of pest management and their high risk aversion (all had small farms, with an average size of 0.5 ha) in pest control, farmers' over estimation of crop yield losses due to pest problems and very inelastic pesticide use response to the pesticide price were inevitable.

The results showed also that the average farmer's perception of crop yield losses due to pest-related diseases was nearly twice as much as actual yield loss of productions without any pest control. This indicated that most farmers did not believe the recommendations and prescriptions on the pesticide products labels, which they commonly regarded as too low a dosage.

The farmers' limited knowledge of pest management, perception of very high crop yield losses, and very inelastic pesticide price response indicated that the effort to convince farmers to reduce their extent of pesticide use mainly relies on the factors that could significantly reduce the farmers' risk aversion. These may include pest management related information, education, training, and extension services. Increasing farmers' awareness of the pesticides' hazard to the environment and human health should be included in the local extension activities in order for the farmers to partially internalize the externalities of pesticide use. The results presented in this study raise some questions on the services currently provided by Agricultural Extension System, a public extension system that has been participating heavily in pesticide marketing activities as a results of the financial crisis.

The price response was surprising low and also much lower than that found in a similar study of Southeast Asian countries. A very low price responsiveness of pesticide use by farmers implies that the incentive policy (tax and price), to become effective, should focus on pesticide production or factory level. As availability of better quality pesticide is the other important determinant of pesticide use, policies to encourage the development of new and improved pesticides are needed both at production/factory and marketing levels.

The government has exerted efforts to regulate pesticide production, marketing, and applications since the 1970s. Considerable progress had been made in the past regarding introducing less persistent compounds as substitutes for highly hazardous pesticides and the safe use and management of pesticides. However, as experience has shown, simply promulgating rules and regulation is not enough to guarantee improvements in the quality of pesticide products in the markets and their proper and safe use. Methods of farmer's handling and application practices of pesticides have not changed. Many highly hazardous pesticides were still used by farmers for pest control. Hence, more conducive and concrete policies, regulations, and enforcement system are required.

Identifying alternatives to current agricultural chemical pesticide practices as a way of reducing pollution is also of critical importance in China. It had been shown that host-plant resistance is a productive but under utilized input (Widawsky, et al., 1998). As a substitute for pesticides, improvements in host-plant resistance could lead to substantial savings in pesticides without reducing crop yield. However, the field survey revealed that only a few farmers considered the available host-plant resistance in making pesticide use decisions (mainly due to lack of knowledge of host-plant resistance). While the concept of integrated pest management (IPM) has gained strong support among environmental groups, extending IPM technology is facing a greater challenge as the opportunity cost of farm labor rises with the development of the non-farm sector in rural China.

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Appendix Table 1. Estimated parameters for frequency of farmers' pesticide application per rice growing season in Zhejiang province.

	Frequency (times)	Frequency (times)	Ln (times)
Variables	Model I	Model II	Model III
Intercept	7.60 (1.31)***	8.90 (4.26)**	1.89 (0.60)***
Farmer's perception on yield loss	2.32 (0.77)***	2.32 (0.79)***	0.35 (0.11)***
Average mixed price of pesticides (AMPP)	-0.02 (0.03)		
Ln (AMPP)		0.09 (0.44)	0.01 (0.06)
Information from ATES	0.08 (0.33)	0.12 (0.34)	0.02 (0.05)
Ln (Rice area)		0.67 (0.27)**	0.08 (0.04)**
Rice area	0.18 (0.04)***		
Income/person	0.00005 (0.00006)		
Ln (Income/person)		-0.21 (0.56)	-0.02 (0.04)
Age	-0.0005 (0.0179)		
Ln (Age)		-0.13 (0.80)	0.003 (0.11)
Dummies: Double-season later rice	2.85 (0.41)***	2.98 (0.42)***	0.43 (0.06)***
Single-season middle rice	0.65 (0.68)	0.86 (0.69)	0.12 (0.10)
Single-season late rice	1.19 (0.41)***	1.08 (0.43)**	0.14 (0.06)**
Higher than middle school	-0.07 (0.52)	-0.08 (0.54)	-0.02 (0.08)
Male	-0.25 (0.46)	-0.29 (0.48)	-0.004 (0.07)
Village dummies: Zhengbei	-3.26 (0.64)***	-3.18 (0.66)***	-0.40 (0.09)***
Yangzhuang	-3.66 (0.63)***	-3.52 (0.65)***	-0.49 (0.09)***
Yushanwu	-1.05 (0.57)*	-0.92 (0.62)	-0.11 (0.09)
R^2	0.49	0.46	0.45
Adjusted R^2	0.45	0.42	0.40

Note: the figures in the parentheses are standard errors of estimates. ***, **, and * denote significance at 1%, 5% and 10%, respectively.

Appendix Table 2. Estimate of BUN abnormalities of rice farmers in the sampled villages of Zhejiang province.

	BUN abnormality of rice farmers			
	Model I	Model II	Model III	Model IV
Intercept	9.22 (3.95)**	8.58 (3.89)**	9.29 (4.00)**	8.49 (3.94)**
Respondent's characteristics				
Male dummy	-0.39 (0.19)**	-0.38 (0.18)**	-0.36 (0.19)*	-0.36 (0.19)*
Ln(Age)	-0.04 (0.21)	-0.03 (0.21)	-0.07 (0.22)	-0.02 (0.21)
Ln(Smoke)	-0.002 (0.007)	-0.002 (0.007)	-0.003 (0.007)	-0.003 (0.007)
Ln(Drink)	-0.02 (0.01)*	-0.01 (0.01)	-0.01 (0.10)	-0.01 (0.10)
Ln(Weight)	-2.96 (1.21)**	-2.90 (1.21)**	-3.07 (1.23)**	-2.84 (1.21)**
Weight/height	10.28 (3.69)***	9.98 (3.69)***	10.48 (3.72)***	9.91 (3.66)***
Ln (chemical use – kg)				
Ln (Categories I&II)	0.01 (0.02)			
Ln (Categories III&IV)	0.11 (0.07)			
Ln (I+II+III+IV))			0.003 (0.27)*	
Volume share of I&II (%)			0.48 (0.27)*	
Ln(Chemical cost – yuan/year)				
Ln (Categories I&II)		0.01 (0.01)		
Ln (Categories III&IV)		0.18 (0.08)**		
Ln (I+II+III+IV))				0.0004 (0.0003)
Cost share of I & II (%)				0.32 (0.29)
Ln (Number of applications)	-0.29 (0.19)	-0.33 (0.18)*	-0.11 (0.16)	-0.15 (0.16)
Anji county dummy	0.02 (0.12)	-0.01 (0.12)	0.05 (0.12)	0.04 (0.12)
$Chi^2(10)$	18.63	21.93	19.29	17.81

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