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# AGRICULTURAL DIFFUSE POLLUTION FROM FERTILISERS AND PESTICIDES IN CHINA

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## ABSTRACT

Although contamination of waterbodies by nitrates and pesticides in rural regions as the main element of agricultural diffuse pollution has been gradually realised by agricultural and environmental scientists, and supported by rapidly growing pollution cases, it is still not considered a high priority environmental problem in China because of a lack of efficient monitoring programs to provide systematic analytical data. This paper brings together evidence in terms of surface water, groundwater and the agricultural ecosystem to show the current situation of water contamination related to excess applications of inorganic fertilisers and pesticides on arable land, research on the above topics, and the importance of understanding and support from both the public and government in association with further studies. 

## KEYWORDS

Fertilisers; pesticides; surface water; groundwater; contamination.

## INTRODUCTION

China, with an area of 9.6 million square kilometres, is one of the biggest countries with a very long agricultural history in the world. It only has approximately 133 million ha of arable land, but feeds an enormous population of nearly 1.2 billion which has been growing fast in recent decades.

In order to meet the food demands of such a huge and growing population, agriculture has been becoming extremely intensive by using many more inputs of inorganic fertilisers, and a wide spectrum of pesticide compounds for pest and disease control, to increase crop productivity of arable land and grain production.

Many agricultural and environmental researchers in China have realised the agricultural diffuse pollution caused in water resources from excess fertiliser and pesticide applications. In rural regions 90% of inhabitants rely on shallow groundwater in wells as their potable water supply, particularly in areas of intensive paddy production in the southern part of China which has a groundwater table of 0.2-10.0 m. In consequence, the quality of surface water and groundwater deteriorates due to increased concentrations of nitrates and various artificial organic chemicals found in them. Such unexpected contamination poses a potential hazard to public health. Therefore, it is not surprising that a number of regions with intensive irrigated agriculture suffer from several kinds of regional diseases like gastric cancers and pains which are quite frequent in coastal areas (Ma, 1979; Wang, 1979).

More and more literature has reported that nitrate and pesticide contamination of waterbodies has become common in China, representing the most important threat to groundwater resources, and such contamination is significantly related to excessive and irrational applications of inorganic fertilisers and pesticides on arable land (Guo, 1987).

## METHODS

This paper brings together national agricultural statistical data from different years and research results from specific sites suffering from water resource contamination in terms of surface water, groundwater, and the agricultural ecosystem. The main objective of this work is to show the current situation of water resource contamination relating to or resulting from excessive applications of inorganic fertilisers and pesticides in agricultural practices, development of research on these topics, and the importance of understanding and support from both the public and government.

## RESULTS AND DISCUSSION

### Fertilisers

Since the dramatic development of fertiliser manufacture in the 1970s, fertiliser utilisation has increased 5-6 fold in China. The consumption of fertilisers was 21.95 million tons in 1989, including N of 15.92 million tons, $P_2O_5$ of 4.53 million tons, and $K_2O$ of 1.5 million tons. The average rate of nitrogen application was 191.6 kg/ha.a, 3.55 times the world average rate of 53.9 kg/ha.a (Sun, 1995). The average ratio of inorganic fertiliser application in 1990 was 1N: 0.28P: 0.09K, much lower compared with the world average ratio of 1N: 0.5P: 0.5K. Table 1 shows the applications of inorganic fertilisers in the southern part of China.

Table 1. The applications of inorganic fertilisers in China (not published)

| Province | 1978 | | 1984 | | 1993 | |
|---|---|---|---|---|---|---|
| | Amount ( AI*, MT** ) | Rate ( kg/ha.a ) | Amount ( AI, MT ) | Rate ( kg/ha.a ) | Amount ( AI, MT ) | Rate ( kg/ha.a ) |
| Jiangsu | 0.75 | 162.0 | 1.57 | 339.0 | 2.50 | 349.5 |
| Anhui | 0.31 | 69.0 | 1.01 | 228.0 | 1.78 | 228.0 |
| Hubei | 0.32 | 85.5 | 0.89 | 244.5 | 1.83 | 321.0 |
| Hunan | 0.55 | 159.0 | 0.83 | 246.0 | 1.48 | 265.5 |
| Jiangxi | 0.23 | 91.5 | 0.47 | 199.5 | 0.94 | 211.5 |
| Zhejiang | 0.37 | 19.5 | 0.69 | 384.0 | 0.86 | 358.5 |
| Fujian | 0.23 | 18.0 | 0.50 | 393.0 | 0.92 | 385.5 |
| Guangxi | 0.32 | 126.0 | 0.50 | 192.0 | 1.05 | 187.5 |
| Guangdong | 0.58 | 18.0 | 1.04 | 333.0 | 1.81 | 346.5 |
| Total | 3.66 | 132.0 | 7.50 | 276.0 | 13.16 | 289.5 |
| China | 8.84 | 88.5 | 17.40 | 178.5 | 31.52 | 193.5 |

* AI: active ingredient; ** MT: million tons.

In China, the dominant forms of fertilisers applied on agricultural land are urea, ammonium hydrocarbonate ($NH_4HCO_3$), superphosphate, Ca-Mg phosphate and chlorinated potassium.

According to the published data of many studies carried out in China, 33.3-73.6% of applied N fertiliser is lost each year with an average loss rate of 60% in arable land, including 20% by nitrogen gas emission, 15%

by denitrification, 10% by soil leaching, and 15% by agricultural land drains and runoff (Zhang, 1985; Zhou *et al.*, 1985; Liu, 1988).

*Surface water contamination.* Surface water contamination by inorganic fertilisers through agricultural land drains and runoff is one of the main kinds of agricultural diffuse pollution. Consequently, many nutrients, including nitrogen and phosphorus, enter the surface water and increase eutrophication of lakes and coastal waters resulting in accelerated reproduction of algae and other organisms, a decrease of dissolved oxygen, and deterioration of water quality. According to a recent survey, 12.7% of main streams and 55% of branch streams of large rivers in China are polluted with eutrophication occurring frequently.

Phosphorus contamination from agricultural land is a major concern of many environmental researchers since it is significant in the composition of nucleic acids of organisms, and a small change in its concentration in the surface water system can invoke a big change in water quality.

The amounts of nutrients discharged by runoff from dry land are different in different parts of China (Table 2), they are certainly dependent on precipitation in a given region.

Table 2. Nutrient element discharges by runoff from dry land in China

| Region | Province | N (kg/ha.a) | P (kg/ha.a) | Reference |
|---|---|---|---|---|
| Dong-hu lake | Hubei | 1.2 | - | Peng and Chen, 1988 |
| Tai-hu lake | Jiangsu | 11.8 | - | Ma *et al.*, 1997 |
| Chao-hu lake | Anhui | 30.5 | 2.39 | Peng and Chen, 1988 |
| Fulin | Sichuan | 11.45 | 1.17 | Chen and Huang, 1991 |

In Tai-hu lake region, the recommended application rates of nitrogen and phosphorus fertilisers on arable land with a cropping system of rice-wheat rotation are 345 kg/ha.a and 18 kg/ha.a, respectively. The average concentration of nitrogen in runoff and the average amount of nitrogen discharged by runoff from paddy fields are 7.4 mg/l and 31.6 kg/ha.a, respectively (Ma *et al.*, 1997).

*Groundwater contamination.* Nitrate leaching through soil horizons from agricultural land to increase $NO_3$-N concentrations is the main cause of deterioration of underlying groundwater quality. The leaching of nitrate in agricultural land is significantly dependent on precipitation, soil properties, N fertilisers, methods and rates of fertiliser applications, and crop cover.

In China, the loss of N through leaching ranges from 8.50% to 28.70% (Shen, 1992; Zhang, 1985; Zhu, 1983a; Zhou, 1992). From north to south, there are many contamination cases reporting that $NO_3$-N concentrations in groundwater underlying intensive agricultural land exceed the maximum WHO guideline level of $NO_3$-N in groundwater, 10 mg/l (Table 3).

Table 3. Groundwater contamination by nitrate in China

| Region | Province | Maximum $NO_3$-N concentration in groundwater (mg/l) | Reference |
|---|---|---|---|
| Yuanmingyuan | Beijing | 28.00 | Jiang and Tang, 1984 |
| Tai-hu lake | Jiangsu | 79.35 | Ma, 1987 |
| Matan | Ganshu | 290.6 | Zhang et al., 1990 |
| West suburb | Beijing | 16.67 | Eryang et al., 1996 |
| Zhangzhou | Fujian | 16.80 | not published |
| Doudian | Beijing | 30.14 | Wen, 1990 |
| Hangzhou | Zhejiang | 175.00 | Wu, 1988 |

For example, Matan aquifer, located in the centre of Lanzhou city, is the main source of drinking water supply for this city. The average concentration of $NO_3$-N in groundwater was 3.8 mg/l in 1965. In 1988, it reached 69.4 mg/l, 18.26 times that of 1965. According to the geographical conditions of this aquifer, the water wells are classified into 3 types: near River Huanghe, near agricultural land, and in agricultural land. Figure1 shows the changes of $NO_3$-N concentrations in different wells during the period from 1964 to 1988 and indicates that agricultural practices, in terms of applications of inorganic fertilisers on land growing vegetables, are the dominant cause of $NO_3$-N contamination of groundwater.

Other researchers (Zhu, 1983b; Chilton, 1994, Eryang *et al.*, 1996) have suggested that there is a significant relationship between applications of nitrogen fertilisers in intensive cultivation and nitrate concentrations in underlying groundwater. Consequently, many studies carried out in China focused on $NO_3$-N leaching from soil horizons in agricultural land. The results indicated that the factors affecting leaching of soil $NO_3$-N are precipitation, soil properties, forms of N fertilisers, methods and amounts of application, and crop cover, and 8.5% - 28.7% of applied nitrogen is lost by leaching (Shen, 1992; Zhang, 1985; Zhu, 1983a; Zhou, 1992).

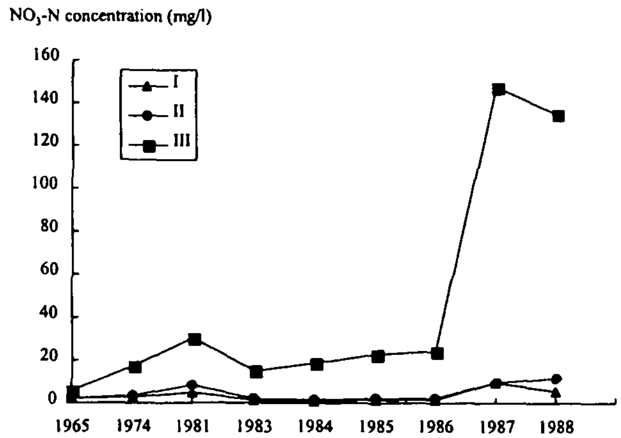


Figure 1. The $NO_3$-N concentrations of groundwater in wells (I) near River Huanghe, (II) near agricultural land, and (III) in agricultural land in Matan aquifer (Zhang *et al.*, 1990).

Table 4. Nitrate lost through leaching from red soils derived from different parent rocks: application rate of N fertilisers is 112.5 kg/ha.a and the crop is ryegrass (Shen, 1993)

| Soil type | Treatment | $NO_3$-N lost through leaching (kg/ha.a) |
|---|---|---|
| Red soil derived from sandstone | Fertilisation | 44.48 |
| | Fertilisation and cropping | 22.02 |
| Red soil derived from Quaternary red clay | Fertilisation | 42.84 |
| | Fertilisation and cropping | 39.62 |
| Red soil derived from basalt | Fertilisation | 10.36 |
| | Fertilisation and cropping | 6.80 |
| Red soil derived from granite | Fertilisation | 42.68 |
| | Fertilisation and cropping | 5.90 |

Eryang *et al.* (1996) suggest that nitrate contamination of groundwater occurs when the application rate of N fertilisers reaches or exceeds 225 kg/ha.a in the Beijing region. Sun (1993) carried out a 7-year plot experiment to indicate that nitrate is the main component of nitrogen leaching in drainage water, and that nitrogen concentration in drainage water is significantly correlated to application rates of nitrogen fertilisers. When application rates are 150 kg/ha.a and 300 kg/ha.a, the losses through leaching from a 1m-depth soil matrix are 36 kg/ha.a and 79.5 kg/ha.a, respectively. Shen (1993) pointed out that the amount of nitrate lost through leaching from four red soils in the southern part of China depend on cropping systems and soil types (Table 4). Ma *et al.* (1997) produced results which show that the average amount of nitrogen lost through leaching from paddy fields in Tai-hu lake region is 10.4 kg/ha.a, and such losses differ according to soil types, precipitation, and the irrigation regime.

*Degradation of agricultural ecosystem.* Due to the long-term excessive utilisation of inorganic fertilisers with incorrect and unbalanced application ratios, without farmyard manure applications, and for the sole purpose of increasing crop production, the agricultural ecosystem degrades by declining in soil organic matter content, holding water capacity, nutrients, and populations of effective micro-organisms, and increasing in soil bulk density, soil salt content, and pest populations. In order to prevent crop production suffering from agricultural degradation, more fertilisers are applied onto fields, thus accelerating the degradation of the agricultural ecosystem, and dramatically increasing the loss of fertilisers from agricultural land.

The most vital evidence of agricultural ecosystem degradation is that the crop efficiency of fertilisers declines. In the 1980s, 1 kg of nitrogen fertiliser applied on paddy fields only produced an increase of 9.1 kg rice, just half of the 1960s value (Lin, 1989). In the black soil region of Haironjiang province, the crop efficiency of inorganic fertilisers was 14 to 16 kg in the 1960s, but only 6 kg in the 1980s (Xie, 1991). Wu (1989) pointed out that application of inorganic fertilisers on paddy fields in the long term could increase nitrate lost through leaching twice as much compared with long-term fertilisation using organic manure. Furthermore, excessive applications of inorganic fertilisers on agricultural land could increase the occurrence of infectious diseases of crops (Hu, 1989; Tan, 1989).

<u>Pesticides</u>

Prior to 1979, agricultural scientists considered that the utilisation of pesticide compounds formed an integral part of modern agriculture, and might assure farmers high yields and good quality of crops. However, all pesticide compounds pose a significant environmental health hazard to the public since they, to a certain degree, remain toxic in the environment.

The 1979 surveys of drinking water and groundwater in the United States indicated that the problems of water contamination by pesticides occurred over widely distributed areas (USEPA, 1987), though concentrations of pesticides in most cases were well below the health advisory guideline levels published by the USEPA.

From 1949 on, the consumption of pesticides in China increased rapidly, 1920 tons in 1952, 537,000 tons in 1980, and 271,000 tons in 1989 after the manufacture of organic chlorinated pesticides ceased at the beginning of the 1980s. The average rate of pesticide application is generally 2.82 kg/ha.a of active ingredient. In general, less than 10% of pesticide applications reach the target area, and a significant portion remains for some time in the soil. This can be leached, either directly to groundwater or, in less permeable soils, via land drains and runoff to surface watercourses.

*Surface water contamination.* Most pesticide compounds have a water solubility in excess of 10 mg/l, and it results in a significant possibility of pesticide transport to the surface water system by agricultural land drains and runoff. During the period from the 1970s to the 1980s, research on surface water contamination by pesticides focused on organic chlorinated pesticides like DDT and HCH (Table 5).

*Groundwater contamination.* The leaching of pesticides is the first aspect of their environmental behaviour in the soil to be addressed when pesticide groundwater contamination is discussed. Both the mode of application and action of pesticides are important factors in relation to soil leaching, since those targeted at plant roots and soil insects are much more mobile than those acting directly on plant vegetation (Foster *et al.*, 1991). Chemical reactivity of organic pesticides with the soil matrix may also play an important role in reducing the amount of pesticide residues in soils available for leaching, including adsorption which is much more related to soil organic matter or clay mineral content, and degradation expressed by the soil half-life, as a result of the generation of less soluble residues.

Table 5. Concentrations of pesticides in waterbodies in China (µg/l)

| Site | Province | Year | DDT | HCH | Reference |
|---|---|---|---|---|---|
| River Huangpu | Shanghai | 1978 | - | 0.9-65.8 | Zhang, 1989 |
| Beiyangding | Hebei | 1975 | - | 0.12-0.3 | Zhang, 1989 |
| River Jialing | Sichuan | 1977 | - | 0.14-0.80 | Zhang, 1989 |
| River Huanghe | Qinghai | 1974 | - | 80 | Zhang, 1989 |
| Offshore | Jiangsu | 1976 | - | 0.1-0.4 | Zhang, 1989 |
| Reservoir Guanting | Beijing | 1972 | - | 0.357 | Zhang, 1989 |
| Tai-hu lake | Jiangsu | 1977 | - | 3.89 | Qu, 1989 |
| Grand Canal | Hebei | 1979 | 0.04-0.12 | 5.00-0.63 | Pesticide group, 1983 |
| River Xiang | Hunan | 1979 | - | 2.65-0.55 | Zhang, 1983 |

When pesticide compounds pass through agricultural soils, they enter the vadose zone which contains a much smaller proportion of organic matter and minerals, has a greatly reduced population of micro-organisms, and generally holds the groundwater table. Therefore, the mobility and persistence of all pesticides should be expected to be many times greater in the vadose zone than in an agricultural soil.

Since the cropping systems in China are, to a great extent, dependent on climatic and geographical conditions, the northern part which is dominated with dry land agriculture utilises alachlor, lindane, aldicarb, and atrizine in wheat, corn and cotton fields, the southern part which is dominated with paddy cultivation uses organic chloride, nitrogen, and phosphorus pesticides, including DDT, DDD, 1605, dimehypo, chlordimeform, methamidophos and omethoate, in rice fields.

In the southern part, a contamination case in Hubei province indicated that the maximum concentrations of 1605 and DDT in village wells for potable water supply exceeded 1.125 mg/l and 0.44 mg/l which were detected in 1988 (Wei, 1988), respectively, as a result of which many wells were closed due to the troublesome concentrations of pesticides. DDT and HCH were also detected in groundwater in Nanchang county, Jiangxi province, with concentrations of 0.16-0.55 µg/l and 0.05-0.19 µg/l, respectively (An, 1992). A herbicide, alachlor, was detected in monitoring wells with concentrations of 5.1 µg/l after 129 days of application in cotton fields in Nantong county, Jiangsu province, exceeding the maximum USEPA acceptable guideline level of 2.0 µg/l in groundwater (Shan, 1994). A recent study on groundwater contamination of pesticides showed that HCH concentrations ranged from non-detectable to 0.074 µg/l, and DDT from non-detectable to 0.005 µg/l (two of the pesticides banned for over 20 years in China), dimehypo from 0.10 to 2.62 µg/l, and delachlor from 3.80 to 16.19 µg/l in groundwater underlying a paddy field in Jiangpu county, Jiangsu province.

Chlordimeform, banned in China since 1991, is an insecticide applied in paddy fields to control pests during rice growing. However, it is still used by some farmers and detected in shallow groundwater from wells for domestic water supply in the southern part of China (Table 6). Concentrations of chlordimeform exceed the EC maximum admissible concentration for any individual pesticide compound of 0.1 µg/l in drinking water in 30.77% of monitoring wells.

In the northern part, pesticide contamination cases are mostly reported from wells near cotton fields. The total amount of aldicarb, aldicarb sulfoxide, and aldicarb sulfone of 0.19 µg/l was detected in well water near cotton fields in Anyang county, Henan province in 1984. This value is much higher than the monitoring result of 0.03 to 0.10 µg/l in Jing county, Hebei province in the same year (Mu *et al.*, 1987).

Table 6. Chlordimeform in groundwater in the southern part of China (not published)

| County | Province | Soil | Concentration ($\mu g/l$) |
|---|---|---|---|
| Nanchang | Jiangxi | red soil | N.D. |
| Yujiang | Jiangxi | red soil | 0.03 |
| Ningdu | Jiangxi | red soil | 0.13 |
| Xinguo | Jiangxi | red soil | 0.79 |
| Qiyang | Hunan | red soil | 0.04 |
| Hennan | Hunan | red soil | 0.02 |
| Wuming | Guangxi | lateritic red soil | 0.02 |
| Xinan | Guangxi | red soil | 0.02 |
| Zhangzhou | Fujian | lateritic red soil | 0.03 |
| Zhaoan | Fujian | lateritic red soil | 0.09 |
| Dongguan | Guangdong | lateritic red soil | 0.11 |
| Kaiping | Guangdong | lateritic red soil | 0.03 |
| Xuwen | Guangdong | latosol | 0.21 |

*Degradation of the agricultural ecosystem.* Until recently, efforts to improve agriculture concentrated on increasing crop yields, mainly through the use of 'improved' seeds of 'high-yielding' varieties, which respond favourably to fertilisers and irrigation, but which demand pesticides, fungicides and selective herbicides to protect them. If the economics are right, if there is no problem associated with the pesticides, all may be fine. Unfortunately, there are usually side effects when pesticides are used, and a crop which lacks resilience to pests, disease and environmental fluctuations may not be a desirable thing in the long term.

The long-term effects of pesticide use on the environment, particularly within the soil, are not clear. There may be an insidious loss of vital soil organisms which play important roles in decay, nitrogen fixation, the sulphur cycle and/or are of significance in symbiotic relations with crops. Predatory organisms, like insect-eating birds, which destroy pest organisms, are likely to be affected by pesticides, probably because they are carnivores at the top of the food chain. The long-term effect may be a temporary kill of pests, which may then develop a resistance to the pesticide, a more permanent kill of predators and a resulting 'boom' in pest numbers. Some pesticides like propanil can inhibit nitrification processes in soils. In consequence, they will reduce the nitrogen uptake efficiency of applied nitrogen fertilisers by crops, and accelerate nitrogen losses by leaching and runoff from agricultural land (Hu, 1993). Therefore, the long-term utilisation of pesticides, to some degree, could negatively affect the functions of the agricultural ecosystem.

## CONCLUSIONS

The contamination of water resources by excessive applications of fertilisers and pesticides is very common in China, and is mainly dependent on climatic conditions, agricultural practices, and application methods and amounts of fertilisers and pesticides on arable land. Generally, agricultural diffuse pollution in the northern part, in terms of inorganic fertiliser application, is much more severe than in the southern part since groundwater quality in the northern part of China is deteriorating due to high concentrations of nitrates.

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## REFERENCES

An, F. C. (1992). Determination of pesticides and other organic substances in groundwater of Liantong town of Jiangxi province. *Advances in Environmental Science (Chinese)*, **13**(2), 54-57.

Chen, X. P. and Huang, S. D. (1991). Discharges of agricultural contaminants by runoff from dry land in Fulin region, Sichuan province. *Environmental Science (Chinese)*, **12**(3), 75-79.

Chilton, P. J., Lawrence, A. R. and Stuart, M. E. (1994). The impact of tropical agriculture on groundwater quality. In: *Groundwater Quality*, Nash, H. and McCall, G. J. H. (eds), Chapman and Hall, pp. 113-122.

Eryang, X. H., Zhu, M. Q. and Chui, J. (1996). Fertilisation and water pollution control in water conservation region in Beijing. *Agricultural Environmental Protection (Chinese)*, 15(3), 107-110.

Foster, S. S. D., Chilton, P. J. and Stuart, M. E. (1991). Mechanisms of groundwater pollution by pesticides. *J. Inst. Water and Environ. Managmnt.*, **5**, 185-193.

Guo, Z. K. (1987). Environmental issues related to nitrogenous fertilisers, *Agricultural Environmental Protection (Chinese)*, **6**(4), 25-27.

Hu, G. R. (1993). Pesticide contamination and agricultural micro-organisms. *Environmental Pollution and Control (Chinese)*, **15**(3), 24-27.

Hu, R. C. (1989). Rational fertilisation and disease control. *Soils and Fertilisers (Chinese)*, **2**, 46-47.

Jiang, D. A. and Tang, Y. D. (1984). Survey of groundwater contamination by nitrate in Yuanmingyuan region. *Environmental Science (Chinese)*, 5(4), 27-31.

Lin, B. (1989). 32-year study on fertiliser application experiment in China. *Soils and Fertilisers (Chinese)*, **5**, 7-11.

Liu, J. T. (1988). Nitrogen dynamics in cotton ecosystem by $^{15}N$. *Rural Ecological Environment (Chinese)*, **1**, 43-46.

Ma, L. S. (1979). Nitrosamine and cancers. *Environmental Protection (Chinese)*, **5**, 40-43.

Ma, L. S. (1987). Study on water environment pollution of nitrate and nitrite in Tai-hu Lake region. *Chinese J. Environmental Science*, **2**, 6-10.

Ma, L. S., Wang, Z. Q., Zhang, S. M., Ma, X. F. and Zhang, G. Y. (1997). Pollution from agricultural non-point sources and its control in river system of Tai-hu lake region, Jiangsu. *Acta Scientiae Circumstantiae*, **17**(1), 39-47.

Mu, H. H., An, F. C., Liu, W. O. and Chen, X. W. (1987). Residues of aldicarb and its metabolites in water. *Environmental Science (Chinese)*, **8**(2), 73-76.

Qu, G. P. (1989). *China Environment in 2000*. Economic Daily Press, Beijing, 1989.

Peng, J. X. and Chen, H. J. (1988). *Surface Water Eutrophication and Control*. China Environment Press, Beijing, 1988.

Pesticide Group of Institute of Environmental Chemistry, Academia Sinica (1983). Residues of organic chlorinated pesticides in Canal Ji. *Environmental Science (Chinese)*, **4**(1), 12-15.

Shan, Z. J. (1994). Influence of a herbicide alachlor on groundwater quality. *Chinese Journal of Environmental Science*, **14**(1), 72-78.

Shen, J. W. (1992). Contamination of groundwater by applications of fertilisers and pesticides and waste water irrigation. *Agricultural Environmental Protection (Chinese)*, **11**(3), 137-139.

Shen, R. F. (1993). Leaching of fertiliser ions in red soils: laboratory soil column and field lysimeter studies. PhD thesis, Department of Material Cycling of Pedosphere, Institute of Soil Science, CAS.

Sun, S. R. (1993). Relationship between precipitation and nitrogen concentrations in soil leachate. *Soils and Fertilisers (Chinese)*, **2**, 8-10.

Sun, P. L. (1995). Environmental pollution from application of nitrogenous fertilisers. *Environmental Pollution and Control (Chinese)*, **17**(1), 38-41.

Tan, Y. C. (1989). Relationship between agroecosystem and pests and diseases in paddy fields. *Journal of Ecology (Chinese)*, **8**(2), 38-40.

USEPA (1987). Pesticide pollution in groundwater in the USA. *Agricultural Chemicals in Groundwater*, pp. 13-48.

Wang, Y. L. (1979). Determination of nitrate and nitrite in well water in Lin county, Henan province. *Journal of Chinese Medicine: cancers*, **5**, 201-204.

Wei, Z. C. (1988). Application and protection of groundwater resources in Hubei province. *Protection of Water Resources (Chinese)*, **4**, 96-101.

Wen, H. (1990). Nitrate contamination of rural regions in northern plains of China. *Agricultural Environmental Protection (Chinese)*, **9**(1), 1-5.

Wu, D. N. (1988). Types of groundwater contamination and causes in the city of Hangzhou. *Environmental Pollution and Control (Chinese)*, **10**(3), 36-38.

Wu, J. J. (1989). Influence of organic manure and inorganic fertilisers on nutrient cycling in paddy fields. *Chinese Journal of Ecology*, **8**(3), 44-48.

Xie, J. (1991). Soil erosion and control measures in black soil region in Hairongjiang province. *Water and Soil conservation (Chinese)*, **11**(5), 61-64.

Zhang, F. D. (1985). Potential and strategies of fertiliser contamination. *Environmental Science (Chinese)*, **6**(6), 54-58.

Zhang, L. C. (1983). Chemical and geographical characteristics of HCH concentration in River Xiang. *Environmental Science (Chinese)*, **4**(5), 8-13.

Zhang, M. Q., Gao, H. Y. and Wu, K. J. (1990). Environmental conditions of nitrate contamination of Matan aquifer in Lanzhou city. *Environmental Science (Chinese)*, **11**(5), 79-82.

Zhang, Z. B. (1989). *Environmental toxicology of insecticides*. Agricultural Press, Beijing.

Zhou, J. Z. (1992). Environmental issues on exploitation of groundwater resources and control measures. *Advances in Environmental Science (Chinese)*, **13**(3), 1-32.

Zhou, Z. C., Jin, Z. Y., Wang, H. Y. and Sun, W. C. (1985). Pathways of N fertilisers applied in dry land. *Environmental Science (Chinese)*, **6**(6), 2-7.

Zhu, J. C. (1983a). Preliminary study on loss rate of nitrogen leaching. *Environmental Science (Chinese)*, **4**(5), 35-39.

Zhu, J. C. (1983b). Preliminary study on the causes of nitrate contamination of groundwater. In: *Proceedings of Nitrogen Pollution and Nitrogen Cycling in Environment*, Chinese Environmental Science Press, Beijing, pp. 210-217.