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SO_2, NO_X and Acid Deposition Problems in China - Impact on Agriculture

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Summary

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China, one of the most populated countries in the world, has experienced an unprecedented period of industrial development – the rapid growth of the economy resulting in a high demand for energy. More than 75 % of primary energy is supplied by domestic coal which has a high S and dust content. This reliance on coal as the principle source of energy has resulted in air pollution dominated by SO_2, particulates, NO_X and acid rain. In comparison with most of the other developing countries in Asia, China has a higher rate of increase in energy consumption. Although some air pollution control measures are adopted in China, the emission of SO_2 is still one of the biggest in the world. The dramatic increase in vehicle numbers in Beijing city and growing industrial activity have resulted in a 33-fold increase in NO_x emission between 1950 and 1990. Visible injury and growth and yield reductions caused by air pollutants are common phenomena in the fields in and around some industrialized areas in China. Vegetables, fruit trees and agricultural/horticultural crops appear most at risk, since most of them are grown close to the densely populated areas. Recent studies on vegetable species (*Brassica juncea*, *Brassica oleracea*, *Lactuca sativa and Raphanus sativus*) grown in pots at distances from 5 to >20 km downwind of the city of Chongqing showed that in comparison with the 'clean site', >20 km from Chongqing, yields of all four vegetable species at the two sites closest to the city were significantly (45 - 88 %) decreased by ambient air pollution. Few controlled studies have been directed at quantifying the impacts of SO_2 on crops and vegetation in China and even less have attempted to investigate the combined effects of SO_2 and other air pollutants as NO_x. Most of the research has been conducted using unrealistically high pollutant concentrations for a short time period, and little work has been directed at investigating the underlying mechanisms. Therefore, research on i) the mechanisms underlying the impact of chronic exposure at realistic levels of pollutants on growth, physiology,

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yield and quality of crops, and ii) field-based impact assessments to quantify the extent of crop loss due to air pollution in China, in relation to fertilizer practice, are urgently needed.

Introduction

China, one of the most populated countries in the world, has experienced an unprecedented period of industrial development – the rapid growth of the economy resulting in a higher demand for energy than other countries. The total coal consumption was 1052 x 10^6 ton in 1990 and reached 1280 x 10^6 ton in 1995. The raw coal that contains a high rate of sulfur and ashes accounts for more than 75 percent of the total energy consumption, although various kinds of energy such as oil, natural gas, hydropower and nuclear power have been developed in recent decades. In coal consumption, the domestic use of coal in China occupies a higher proportion than in most developed countries, amounting to about 30 or 40 times of that in Japan and the USA. This reliance on coal as the principle source of energy has resulted in air pollution dominated by SO_2, particulates, NO_X and acid rain. And the low energy utilization ratio led to environmental pollution problem too. The energy utilization ratio was about 30 % in China in recent years but about 40 % in Western Europe and more than 50 % in Japan and the USA.

In addition, the dramatic increase in vehicle numbers in some big cities and growing industrial activities have resulted in a high increase of NO_X emission. NO_X annual average concentration in urban areas has increased year by year, and NO_X has become the pollutant of most importance in big cities such as Beijing and Guangzhou.

SO_2 Emission and Acid Deposition

In comparison with most of the other developing countries in Asia, China has a higher rate of increase in energy consumption. Although some air pollution control measures are adopted in China during recent years, the emission of SO_2 is still one of the biggest in the world and the pollution is still rather serious. This has resulted in greater air pollutant emission increase than the average rate of increase in developed countries. It was estimated that Chinese SO_2 emissions account for *ca.* 69 % of the total SO_2 emissions from Asia (KATO 1996).

Fig. 1 shows SO_2 emissions in China during recent years. The highest total SO_2 emissions appeared in 1995 and 1997, which were over 23 x 10^6 ton per year. In 2000 the total amount of SO_2 emissions was 19.95 x 10^6 ton, 16.12 x 10^6 ton from industrial sources and 3.83 x 10^6 ton from municipal sources. The total amount of emission of flue gas and dust was 11.65 x 10^6 ton, 9.53 x 10^6 ton from industrial sources and 2.12 x 10^6 ton from municipal sources. The total amount of emission of industrial ashes and powders was 10.92 x 10^6 ton.

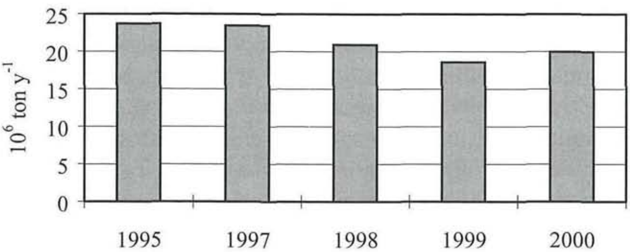

Fig. 1. SO_2 emissions in China during recent years (from Report on the State of the Environment in China (RSEC) 1995 - 2000, Beijing).

Urban air pollutions were very serious during recent years. The air pollutant concentrations in northern cities were higher than in southern cities. For example, in 1997, the national annual average concentration of SO_2 was 66 μg m^{-3}, ranging from 3 to 248 μg m^{-3}. The concentrations exceeded the Chinese secondary air quality standard (SAQ) for SO_2 (which is 60 μg m^{-3}), in 52 % and 38 % of the northern and southern cities, respectively. The annual average concentration of SO_2 in the northern cities was 72 μg m^{-3}, while it was 60 μg m^{-3} in the southern cities. In the northern region, 79 % of the 47 northern cities' annual means were higher than the long-term critical level for agricultural crops, 30 μg m^{-3}. The highest levels of SO_2 were monitored in Taiyuan and Jinan, the average annual concentration of SO_2 reached 248 μg m^{-3} and 173 μg m^{-3} respectively, which were 8.2 and 5.7 times the critical level. In the southern region, 70 % of the 47 southern cities' annual means were higher than the critical level. The highest levels of SO_2 were monitored in Yibin and Chongqing, where the annual mean SO_2 concentration reached 216 and 208 μg m^{-3} respectively, which were 7.2 and 6.9 times the critical level. In 1996 the average air concentration of SO_2 in the cities within the State-Controlled Network was 2 to 418 μg m^{-3}. The average concentration of SO_2 for cities over the country reached 79 μg m^{-3} that of northern cities 83 μg m^{-3} and that of southern cities 76 μg m^{-3} (data from Report on the State of the Environment in China (RSEC) 1995 - 2000, Beijing)

The south of China became the third largest region with heavy acid deposition after Europe and North America. In the last two decades, the area in China affected by acid rain has increased dramatically. In 1993, this area accounted for more than 40 % of the total land area of China. The land seriously affected by acid deposition has extended from 1.75 x 10^6 km^2 in 1985 to 2.8 x 10^6 km^2 in 1993 (WANG & WANG 1995).

The regions with acid rain have remained stable at the end of the 1990s, and were mainly located in the large areas to the south of the Yangtze and to the east of Tibet and Qinghai Plateau, as well as in Sichuan Basin. In mid-China, south China, southwest and east China, there are regions with serious acid rain pollution.

In the northern part, there is acid rain in some places such as Tumen and Qingdao. The area with acid rain accounts for 30 % of the territory in recent years.

In 1999, the pH value monitoring results of the rainfall in 106 cities indicate that the annual pH value of the rainfall was 4.3 - 7.5. There were 43 cities where the annual rainfall pH value was lower than 5.6, accounting for 41 % of the cities that were monitored. In the 59 southern cities of the statistics, the pH value of annual precipitation in 41 cities was less than 5.6 (Fig. 2). The cities with over 80 % acid rain frequency include Huaihua, Jingdezhen, Zunyi, Yibin and Ganzhou. In the northern cities, the annual pH value of the precipitation in Tumen and Qingdao was less than 5.6.

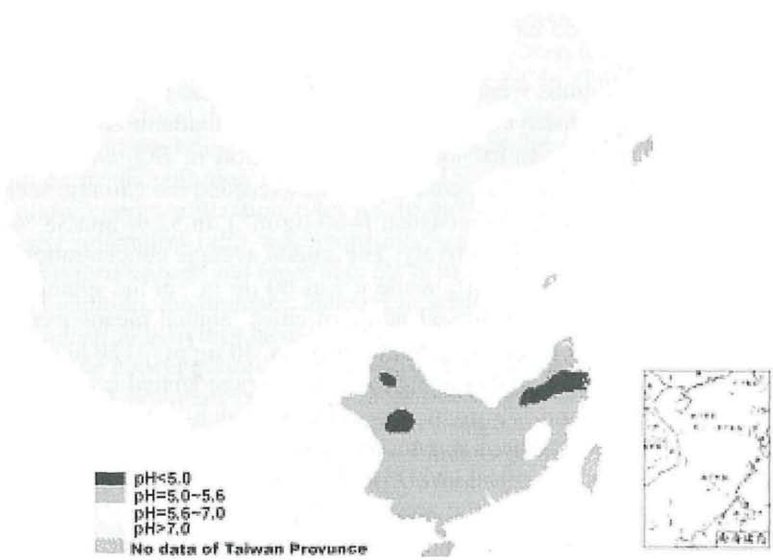

Fig. 2. The distribution of annual rainfall pH over China in 1999 (from Report on the State of the Environment in China (RSEC) 1995 - 2000, Beijing).

Dramatic Increase in Vehicle Numbers and NO_x Pollution

Because of the dramatic increase in vehicle numbers in some big cities and growing industrial activity, NO_X annual average concentration in urban areas has increased year by year, and NO_X has become the pollutant of the most importance in big cities such as Beijing, Guangzhou and Shanghai. Fig. 3 shows the annual variation of the motor vehicle population in Beijing, Shanghai and Guangzhou City. The average annual growth rates of the vehicle population in Beijing, Guangzhou and Shanghai were 16.4, 16.5 and 13.4 %, respectively, since the 1980's, and the contribution of vehicles to CO and NO_X emission of these cities were over 80

% and near 40 %, respectively. The daily average concentrations of NO_X and CO in the city street atmosphere have greatly exceeded the Chinese secondary air quality standard (SAQ), and the pollution situation near streets is more serious than that of other urban areas. The photochemical smog phenomenon already exists in some metropolitan cities and the pollution is getting more and more serious.

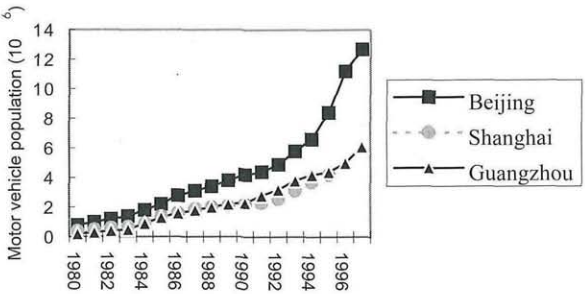

Fig. 3. The increase in motor vehicle population in Beijing, Shanghai and Guangzhou City from 1980 to 1997 (from XIE & al. 2000).

Fig. 4 shows the NO_X emissions in China between 1950 and 1990. By the growing industrial activity and the rapid increase in vehicle numbers, NO_X emissions in China increased 33-fold between 1950 and 1990. According to the results of national air ambient environment monitoring between 1986 and 1995, the daily concentration of SO_2, TSP and micro-dust in ambient air of the cities actually decreased about 10-13 % but the annual average concentration of NO_X increased about 3 %. Nearly 70 % of cities had the increased trend of concentration of NO_X and NO_X has become the most importance pollutant in a few metropolitan cities (WANG & al. 1997, XIE & al. 2000).

In 1997, the national average concentration of NO_X was 45 µg m^{-3}, and ranged from 4 to 140 µg m^{-3}. The annual average NO_X concentration in northern cities was 49 µg m^{-3} and 41 µg m^{-3} in the southern cities. 36 % of the monitored cities could meet the Chinese SAQ for NO_X (which is 50 µg m^{-3}). The bigger cities, with high vehicle numbers, normally exhibit higher NO_X concentrations. In 79 % of the 47 northern cities the annual average concentrations exceeded the long-term critical level for agricultural crops, 30 µg m^{-3}. The highest level, measured in Beijing, was more than 4 times the critical level, 133 µg m^{-3}. In 70 % of the 47 southern cities the annual average concentration was higher than the critical level. The highest levels, measured in Guangzhou and Shanghai, were more than 4.7 and 3.5 times the critical level, 140 and 105 µg m^{-3}, respectively (data from China Environmental Yearbook (ECCEY) 1998, Beijing).

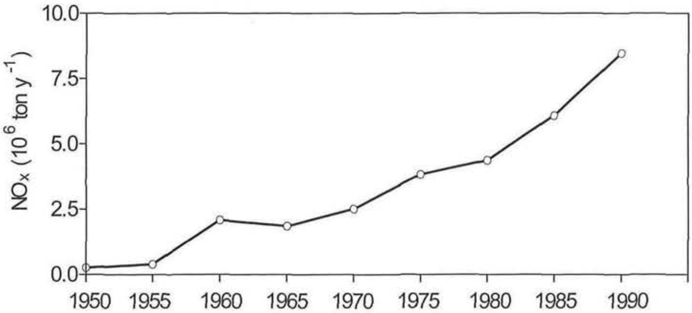

Fig. 4. NO_x emission in China from 1950 to 1990 (from WANG & al. 1997).

Air Pollution in Beijing

The air pollution in Beijing is very serious, and it is the mixed type of pollution caused by the coal burning and vehicle emission. Fig. 5 shows the annual daily average concentrations of ambient SO_2 and NO_X in Beijing from 1981 to 2000. The highest annual daily average concentration of ambient SO_2 appeared in 1991, 132 µg m^{-3}, and the highest annual daily average concentrations of ambient NO_X appeared in 1998, 148 µg m^{-3}. There was a gradual increase in the NO_X con-

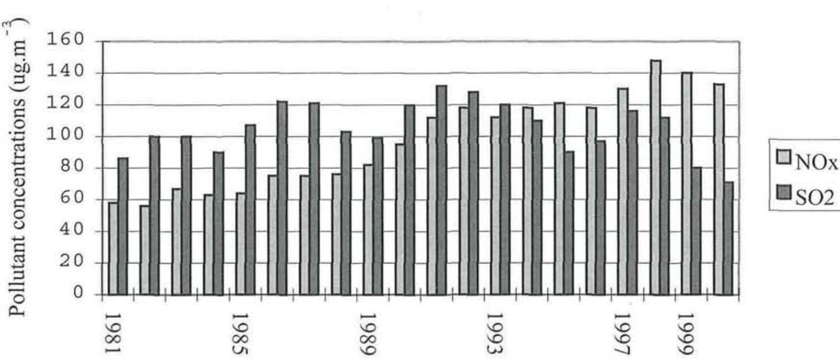

Fig. 5. Annual average concentrations of ambient SO_2 and NO_X in Beijing from 1981 to 2000 (from XIE & al. 2000, BJEPB 2001).

centrations during the last two decades. Since 1994 the concentration of ambient NO_X was higher than the concentration of ambient SO_2 and became the first pollutant in autumn and winter seasons. Fig. 6 shows the SO_2 and NO_X average concentration in Beijing from January 1994 to June 1997. Pollutant levels of SO_2 and NO_X

in winter (November to March) greatly exceeded the Chinese SAQ, because of the winter heating.

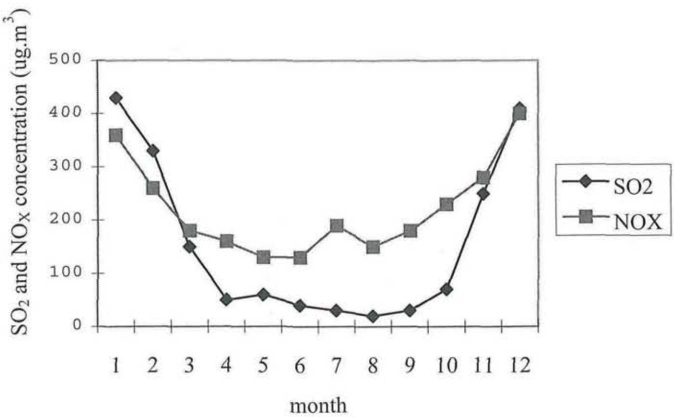

Fig. 6. SO_2 and NO_X average concentration in Beijing from January 1994 to June 1997 (from WEI & LIN 1999).

Air Pollution Effects on Agriculture

Investigations showed that around the big cities and industrial areas, yield and quality of the vegetation is affected by air pollutants. Visible injury and growth and yield reductions caused by air pollutants are common phenomena in the fields in and around some industrialized areas in China (CAO 1990, FLORIG 1997). Vegetables, fruit trees and agricultural/horticultural crops appear most at risk, since most of them are grown close to the densely populated areas. Due to the great demand for fresh fruit and vegetables in the cities, and the poor transportation system in some areas, most fruit and vegetable producing areas are located around the densely populated areas (ZHENG & SHIMIZU 2000).

Acid rain resulting in forest and agricultural decline and damage attracted people's attention from 1980's in southwest China. According to the research report, 46 % of 1500 ha *Pinus massoniana* forest in Nanshan Chongqing, 40 % of *Abies fabri* forest in Emei Mountain, Sichuan province and 96 % of 6000 ha *Pinus armandii* forest in Fenjie County, Sichuan province have damage of SO_2 combining with acid fog, acid rain and consequently the increased susceptibility to insects (LIU & al. 1988b, YU & al. 1990 a,b, MOU & GUO 1992, PU & YANG 1992, QING & al. 1992, SHU & al. 1993, ZHAO & al. 1994, SHEN & al. 1995, BAO 1999). Forest decline and damage from acid rain also occurred in Guangxi, Guangdong and Zhejiang provinces. The estimation (ZHANG & al. 1998a,b, FENG & al. 1999) showed that 19.1 % of the agricultural land in the 7 provinces (Jiangsu, Zhejiang, Anhui, Fujian, Hunan, Hubei and Jiangxi) in southern China was affected by SO_2 and acid rain pollution. The average crop yield reduction due to the combined effects of SO_2 and acid rain was 4.3 % in the middle of 1990s. Vegetable yield was reduced by 7.8 %, wheat by 5.4 %, soybean by 5.7 % and cotton by 5.0 %. In these 7 provinces, 4.2 % of the forest was affected by acid deposition, a total area of 1.28 x 10^6 ha, 62 % was *P. massoniana* Lamb. forest. The average volume loss rate of forest was 13.2 %, with a total loss of 1.01 x 10^6 m^3 (LIU & al. 1988a, YU & al. 1990b, ZHENG 1991, SHEN & al. 1995). Recent research results (FENG 2000) showed that annual crop areas suffering from acid deposition and annual economic losses of crops in 11 provinces (Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Hunan, Hubei, Sichuan, Guizhou, Guangdong and Guangxi) of south China are estimated to be 12.89 x10^6 ha and 4.26 x 10^9 Chinese Yuan, respectively. Annual economic losses of forests due to acid deposition in those provinces were estimated to be 1.8 x 10^9 Chinese Yuan (Table 1).

Table 1. Annual areas, economic losses of crops and annual economic losses of forests due to acid deposition in 11 provinces of south China (FENG 2000).

Province	Annual Areas and Economic Losses of Crops								Annual Economic Losses of Forests		
	Grain crops		Cash crops		Vegetables		Subtotal		Pine trees		Sub total
	10^6 ha y^{-1}	10^9 Yuan y^{-1}	10^6 ha y^{-1}	10^9 Yuan y^{-1}	10^6 ha y^{-1}	10^9 Yuan y^{-1}	10^6 ha y^{-1}	10^9 Yuan y^{-1}	10^6 ha y^{-1}	10^9 Yuan y^{-1}	10^6 ha y^{-1}
Jiangshu	1.788	0.222	0.818.	0.175	0.400	0.280	3.006	0.068	0.017	0.012	0.029
Zhejiang	0.214	0.026	0.170	0.028	0.250	0.231	0.633	0.029	0.100	0.060	0.210
Anhui	1.206	0.273	0.568	0.142	0.219	0.190	1.993	0.061	0.015	0.002	0.009
Fujian	0.084	0.008	0.115	0.007	0.327	0.317	0.525	0.033	0.041	0.056	0.071
Jiangxi	0.047	0.002	0.292	0.054	0.283	0.304	0.622	0.036	0.024	0.093	0.134
Hunan	0.153	0.010	0.372	0.096	0.423	0.497	0.948	0.060	0.030	0.056	0.080
Hubei	1.080	0.195	0.684	0.242	0.427	0.410	2.191	0.085	0.136	0.037	0.067
Sichuan	1.008	0.100	0.713	0.030	0.133	0.060	1.854	0.019	0.049	0.005	0.141
Guizhou	0.310	0.010	0.142	0.010	0.029	0.010	0.482	0.003		0.005	0.054
Guangdong	0.001	0.001			0.312	0.191	0.313	0.019			0.352
Guangxi	0.102	0.020			0.219	0.128	0.321	0.015			0.655
Total	5.229	0.865	3.873	0.785	3.015	2.607	12.88	4.257			1.802

Many field investigations and laboratory studies on the effects of air pollutants on agriculture have been conducted in China since the beginning of 1980's. However, few controlled studies have been directed at quantifying the impacts of SO_2 and NO_X on crops and vegetation in China. Even less have attempted to investigate the combined effects of SO_2 and other air pollutants as NO_X (XIAO 1996). Most of the research has been conducted using unrealistically high pollutant concentrations for a short time period, and little work has been directed at investigating the underlying mechanisms (LIU & al. 1991, ZHOU & al. 1993, DAI & al. 1994). There are a few field fumigation experiments, but continuous air pollutant monitoring data are lacking. For example, ZHENG grew four vegetable species in pots in different locations with 5 km, 10 km and >20 km downwind from the city of Chongqing (ZHENG & al. 1996). Results showed that in comparison with the 'clean site', >20 km from Chongqing, yields of all four vegetable species at the two sites closest to the city were significantly (45 – 88 %) decreased by ambient air pollution. It was also found that the number of aphids on some of the vegetable leaves was significantly higher at the sites closer to the city.

Therefore research on i) the mechanisms underlying the impact of chronic exposure at realistic levels of pollutants on growth, physiology, yield and quality of crops, and ii) field-based impact assessments to quantify the extent of crop loss due to air pollution in China, in relation to fertilizer practice, are urgently needed.

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