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The Status and Countermeasure of Nitrate Pollution Under Double Cropping Systems in China

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Abstract: The multiple cropping is the main agricultural production pattern, including double cropping of rice in south China and double cropping of wheat and corn in north China. Household investigation, typical farmland survey and county statistics inspection were performed to analyze the status and countermeasure of nitrate pollution in China. The result showed that the nitrate rate of underground water was slowly increased, but it was not above the standard of WHO. Under the multiple cropping of winter wheat-summer corn, the nitrate level of irrigation well water had raised year after year since 1991. Some countermeasures should be taken to avoid the nitrate content of underground water, such as increasing the fertilizer use efficiency by taking agronomic measures, according to the local conditions, a reasonable allocation and application of fertilizer and others.

Keywords: Fertilizer, multiple cropping, nitrate pollution.

1. INTRODUCION

With the increased agricultural intensification degree, especially the rising Nitrogen fertilizer application rate, nitrates from agricultural fertilizer could continue to leach into underground water for at least 80 years after the initial use [1]. In China, as early as the 1960s, the problem of nitrate pollution has been a matter of concern, which now has become one of the hotspots. The Chinese farmland loss of nitrogen comes from chemical nitrogen fertilizer entered into the environment accounting for about 4.93 million tons in 2004, including 284 thousand tons of nitrogen to form N_2O and 2.84 million tons of nitrogen to translate into NH_3 emission into the atmosphere, but the nitrogen loss of 1.29 million tons gets into the surface water, and 517 thousand tons enter into the underground water [2].

Nitrate is concentrated rapidly in the surface water and groundwater, continuously expanding the hazards of drinking water resources. Once the nitrate contents in drinking water increased over a certain level, it brings about the direct threat to human health, by damaging the ecosystems directly or indirectly. There were many reports on nitrate pollution of water bodies [3-11]. Meanwhile, the relationship was positive between groundwater nitrate concentrate of grain field and nitrogen fertilizer use level in Beijing suburban [7].

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2. MATERIALS AND METHODS

The research paper focussed on the nitrate pollution of underwater in the multiple cropping regions. Many research methods were adopted to gain the status and countermeasure of nitrate pollution in China, such as household investigation, typical farmland survey, and county statistics inspection. Three planting patterns of winter wheat-summer corn, winter wheat-rice, and double cropping of rice were chosen. Three regions were chosen, which were Yujiang County, Xinxiang County, and Jing County, respectively. Investigation was carried out in 2011. Water samples were selected from the three counties, information was obtained on well depth, crop rotation, and yield and fertilizer application.

The advanced water quality laboratory series HACH-DR/EL 5 was used for the analysis of NO3-N at programmed wavelengths. Data were analyzed using regression analysis.

3. RESULTS

3.1. Nitrate Pollution Caused by Different Planting Patterns

3.1.1. Nitrate Pollution Caused by Double Cropping of Winter Wheat-Summer Corn in Jing County

According to the household investigation results, the water samples of irrigation wells were analyzed; the nitrate rates of irrigation water are shown in Table **1**. Under the conditions of double cropping of winter wheat-summer corn, the nitrate level was between 0.18 and 3.12 mg per liter

Table 1. The changes in nitrate rate of different irrigation well.

Sampling Location	Yield Level	Sampling Date (Month/Year)	Nitrate Content (mg/l)	Well Depth (m)
Village 1	low	5/2011	0.18	40
	high	5/2011	1.01	60
Village 2	low	5/2011	0.77	60
	high	5/2011	1.08	30
Village 3	low	5/2011	0.18	50
	high	5/2011	0.18	50
Village 4	low	5/2011	0.18	30
	high	5/2011	0.63	50
Village 5	low	5/2011	0.75	50
	high	5/2011	0.96	50
Village 3	high	12/2011	3.12	50
		12/2011	1.14	50

Table 2. The surface water nitrate concentration of point paddy fields during the rice growth period.

No.	Nitrogen Fertilizer Rate (kg/ha)	Before Rice Seedling Planting (mg/L)	Seedling Stage (mg/L)	Heading Stage (mg/L)	Filling Stage (mg/L)	Average (mg/L)
1	600	9.95	2.30	10.89	7.52	7.65
2	550	12.69	3.06	6.30	7.83	7.47
3	500	10.80	2.93	6.80	7.25	6.93
4	470	10.17	2.93	6.89	6.89	6.71
5	420	10.26	3.29	8.33	6.57	7.07
6	370	10.31	2.21	7.61	5.94	6.53
7	300	11.07	3.02	6.53	5.94	6.62

(Table **1**). The nitrate levels had great variation for irrigation water by twice testing in a year (first time was May 29, 2011; second time was December 4, 2011). The nitrate rate did not surpass the standards of WHO.

3.1.2. Nitrate Pollution Caused by Double Cropping of Winter Wheat-Rice in Xinxiang County

The nitrate concentration of surface water of paddy-field cause impact on double cropping of winter wheat-rice. After the winter wheat is harvested, all wheat straws were returned to field. The arable land was first irrigated, then plowed and harrowed by tractors. The rice seedlings were planted in the end of June or early July. During the rice growth season, the paddy fields of seven households were chosen, and pointed, and the surface water of paddy field was taken by regular intervals. The time of drawing the water sample was before rice seedling planting, seedling stage, heading stage, and filling stage. The nitrate level is shown in Table **2**.

The results showed that whether it is the different growth stage or the whole growth period of rice, the maximum surface water nitrate contents was only 12.69 mg/L; it conformed wth the WHO standard.

According to the results of nitrate test and the nitrogen fertilizer use level, the model was established as follows (1):

$$y=0.0035x+5.3691 \quad R2=0.7298 \quad r=0.8543^{**} \qquad (1)$$

**y is the nitrate concentration, and x is the fertilizer use level; there was a significant correlationship between them.

Table 3. The water nitrate rate of irrigation well variation in 2011.

Date (M-D)	7-10	7-31	8-10	8-31	9-15	9-30	12-20	4-10	5-20
Nitrate (mg/L)	6.76	5.62	10.29	7.63	6.29	7.17	3.21	7.03	5.04

Table 4. The nitrate rate of different water bodies in Yujiang County (mg/L).

Village	BRSP	HSER	MSER	HSLR	MSLR
Hongyuanwu	0.45	2.15	0.57	0.58	0.02
Panjia	0.31	0.46	0.31	0.06	0.43
Tangjing	0.94	0.65	1.67	0.04	0.59
Xinhelin	1.37	2.86	1.40	0.59	2.80
Huangni	0.54	0.55	1.32	0.55	0.44
Wujia	1.99	0.29	0.41	1.38	0.60

The water nitrate rate of irrigation well.

The investigation of irrigation well for water nitrate contents level began with the wheat planting, and finished by the next year after the wheat harvesting is completed. The water depth of irrigation well was between 40 and 50 meters. The testing nitrate levels are shown in the Table **3**. The results showed that, within one year, the maximum nitrate rate reached only 10.29 mg/L; the other numbers were fluctuated between 3.21 and 7.63 mg/L.

3.1.3. Nitrate Pollution Caused by Double Cropping Rice in Yujiang County

The surface water samples were drawn from a large area. The time of water sample was drawn before rice seedling planting (BRSP), heading stage of early rice (HSER), maturing stage of early rice (MSER), heading stage of late rice (HSLR), and maturing stage of late rice (MSLR). The nitrate testing results are shown in Table **4**. During the growth period of double cropping rice, the nitrate rate in different water bodies was below the standard, but the nitrate levels varied in different locations.

By comparng the three cropping patterns, winter wheat-rice in Xinxiang County was more likely to cause a rapid increase in the nitrate content of groundwater.

3.2. Nitrate Pollution Prevention and Countermeasures

China is facing the challenge of feeding its large sized and increasing population from a limited and decreasing area of cultivated land while striving to achieve a clean and safe environment [12]. The fertilizer-based intensive agriculture brings serious negative effects on the environment [13]. Nitrogen is the basic element of all life on Earth as we know. The need to provide sufficient nitrogen to grow food and support agriculture has governed the rise and fall of civilizations [14]. On the other hand, nitrogen is an important factor of growing pollution; nitrogen is different from other pollutants as a special object [5].

Today, there are many factors that affect the nitrate pollution. The most important factor is the nitrogen fertilizer application level. The nitrogen fertilizers have been heavily used recently, thereby increasing the nitrate rate of water body. Some research showed that the nitrate level of water body has a positive relationship with the nitrogen fertilizer use level [5, 6, 10, and 11]. The application and management of nitrogen fertilizer is imminent.

3.2.1. According to the Local Conditions, a Reasonable Allocation and Application of Fertilizer, Especially Nitrogen Fertilizer That is a Limited Agro-Resource in China

According to the China statistics yearbook of 2002, the fertilizer consumpton reached 42.54 million tons; every hectare of cultivated land used 327.13 kilograms in the same year (Table **5**). In terms of arable land, the fertilizer amount used was the highest in Fujian province; the No. was 818.29 kilograms per hectare. Tibet is the example of lowest use, where the fertilizer application level was only one tenth of Fujian province, which was 82.74 kg/ha.

The planting index (PI) was considered. Different regions had different PI value (Table **6**). Therefore, the fertilizer application levels were figured out by sown areas for every province in 2002 (Table **7**).

Considering the actual agriculture production, there was a difference between FURc and FURs. The FURs of Shanghai municipality is the largest, it was 502.96 kg/ha, whereas the FURs of Heilongjiang province was the lowest; the latter was only about 1/4 of the former.

The model was built based on nitrogen fertilizer application amount and nitrate level of groundwater, for which data came from the investigation of both Wen County, Henan province, Huantai County, and Shandong province, where the yield of double cropping of winter wheat-summer corn was more than 15 tons per hectare. The model is as follows (2):

Table 5. The fertilizer use rate per hectare of cultivated land (FURc) in different Chinese provinces (kg/ha).

Province	FURc	Province	FURc
nationwide	327.13	Beijing	456.53
Shanxi [1]	184.98	Shanghai	644.24
Heilongjiang	104.68	Neimenggu	96.70
Anhui	470.12	Fujian	818.29
Henan	544.62	Hubei	495.61
Guangxi	381.36	Hainan	354.28
Yunnan	186.87	Tibet	82.74
Qinghai	103.92	Ningxia	193.49
Province	FURc	Province	FURc
Tianjin	356.26	Hebei	397.19
Liaoning	263.01	Jilin	204.54
Jiangsu	667.76	Zhejiang	424.88
Jiangxi	366.47	Shandong	557.40
Hunan	466.23	Guangdong	596.23
Sichuan	231.21	Guizhou	142.76
Shanxi[2]	254.94	Gansu	131.55
Xinjiang	209.00		

Note.[1] the capital is Taiyuan City; [2] the capital is Xi'an City.

y=0.0851x-23.283 R2=0.5212 r=0.7219* r0.01=0.765 r0.05=0.632 (2)

*y is nitrate concentration, x is fertilizer use level.

If y=0, then x=273.6 kg/ha

Thereby, once the nitrogen fertilizer application level is over 273.6 kg/ha, the nitrate will start accumulating in the groundwater.

If y=50, then x=861.1

If there is no nitrate pollution, the nitrogen fertilizer use amount must not exceed 861.1 kg/ha.

3.2.2. Rational Fertilization, Depending on the Rules of Different Crop Varieties, Demand Different Fertilizer Kinds

To enhance and improve Chinese people' living standards, the crop types and scopes have been expanded. The fertilization areas could be synchronously enlarged. Considering different soil types, crop varieties, climate, water resources, and agricultural production conditions, the reasonable amount of fertilization must be recommended in order to reduce the negative effects on the environment. However, this work was done in 1980s in China; by that time the application amount of NPK was suitable for the main food crops (Table **8**).

Although the project has already been formulated for about 30 years, the situation has tremendously changed now. The project must therefore, be modified. Firstly, the most soil did not lack potash in China during 1980s. Therefore, the proposal of fertilization project did not include the potash fertilizer. But now that the 1/3 of arable land lack potash nutrient today [15], with the growing crop yields, this trend must be taken seriously; the potash fertilizer use must be increased. Secondly, the crop yield was between 4500 and 6000 kg/ha in 1980s, the main staple crop (wheat, rice, and corn) yield is as much as 7500 kg/ha now. Under the double cropping condition, the annual crop output could reach 15 t/ha. In the high output farming system, the input must be kept at the same pace with output. Thirdly, with the policy reforming and opening of aid, most rural Young men got into the factories of towns and cities and the left behind were women, older man and children. The organic fertilizer had almost not been used in the grain field besides the crop straws returning to the field. So, according to the newly changing production situation, the new project of fertilization should be re-enacted.

The fertilizer usage increased efficiency to some extent on the basis of a reasonable ratio of NPK. The investigation of household in the three double cropping region for the high crops yield of households, came up with the concluson that phosphorus and potash fertilizer account for high percentage

Table 6. The planting index in different provinces of China.

Province	PI (%)	Province	PI (%)
nationwide	119.57	Beijing	92.47
Shanxi [1]	82.71	Shanghai	128.09
Heilongjiang	85.65	Neimenggu	75.79
Anhui	153.60	Fujian	172.95
Henan	171.67	Hubei	147.07
Guangxi	147.22	Hainan	102.1
Yunnan	94.27	Tibet	64.81
Qinghai	69.29	Ningxia	86.64
Province	PI（%）	Province	PI（%）
Tianjin	102.84	Hebei	127.64
Liaoning	90.94	Jilin	88.81
Jiangsu	150.96	Zhejiang	133.53
Jiangxi	175.46	Shandong	139.62
Hunan	201.81	Guangdong	147.16
Sichuan	140.96	Guizhou	97.97
Shanxi[2]	81.74	Gansu	74.15
Xinjiang	93.61		

Note. [1] the capital is Taiyuan City; [2] the capital is Xi'an City.

of the chemical fertilizer used in the households leading to high yields; the ratio of NPK was reasonable.

For instance, in the households for double cropping of rice region, the nitrogen, phosphorus, and potassium fertilizer application level were ranging from 45.0 to 375.0, from 0.0 to 230.0, and from 0.0 to 210.0 kg/ha, respectively. There were 4 households without application of phosphorus fertilizer. Another 4 households did not use the potash fertilizer during double cropping rice production. As for the ratio of NPK, in combination with the yield level, the household was divided into the low, medium, and high yield; the ratio of NPK is shown in Table **9**.

Among 30 households in the region of double cropping of winter wheat-summer corn in Jing County, the principle fertilzer used was based on nitrogen, phosphorus and potassium. The nitrogen peak was more than 1.9 times that of the lowest. The highest amount of phosphate was more than 3 times that of the lowest. There was 1 household that did not use potash fertilizer for the wheat and corn production. In the other 29 households, the maximum potash fertilizer application used was more than 6.6 times that of the lowest. The production of nitrogen, phosphorus, and potash fertilizer is shown in the Table **10**.

Among 30 households in the region of double cropping of wheat-rice, there were 3 households that did not use phosphorous fertilizer. There were 5 households without the use of potash fertilizer. However, the yield of wheat and rice was not low. The wheat straws must be returned to the fields. To a certain extent, the wheat straws containing NPK nutrients could make up for the nutrient elements depletion during the crop production.

If the ratio of NPK is not reasonable, not only does this lead to the waste of nitrogen fertilizer and increased nitrogen loss, but also caused the water body polluted with nitrate. The experimental results lasting over 18 years (1978-1996) on Malan farm, Xinji City, Hebei province, showed that the nitrate rate of soil was higher in the single nitrogen fertilizer application treatments. On the other hand, if the organic manure use overloaded, the soil contained high rate of nitrate, thereby exerting the same effects on the groundwater [10].

3.2.3. Increasing the Fertilizer Use Efficiency by Agronomic Measures

Optimization of the fertilization methods, such as using ammonium bicarbonate and urea as the basal fertilizer in the rice production, when they were topdressing, gave the nitrogen use efficiency to be 17 % and 28% , respectively. At the same time, the nitrogen loss could reach from 47 % to 70% respectively. Moreover, if they were buried material fertilizers or mixed with organic fertilizer, the nitrogen use

Table 7. The fertilizer use rate per hectare of sown area (FURs) in different provinces of China (kg/ha).

Province	FURs	Province	FURs
nationwide	273.59	Beijing	493.71
Shanxi[1]	223.65	Shanghai	502.96
Heilongjiang	122.22	Neimenggu	127.59
Anhui	306.07	Fujian	473.14
Henan	317.25	Hubei	336.99
Guangxi	259.04	Hainan	346.99
Yunnan	198.23	Tibet	127.67
Qinghai	149.98	Ningxia	223.33
Province	FURs	Province	FURs
Tianjin	346.42	Hebei	311.17
Liaoning	289.21	Jilin	230.31
Jiangsu	442.34	Zhejiang	318.19
Jiangxi	208.86	Shandong	399.23
Hunan	231.02	Guangdong	405.16
Sichuan	164.03	Guizhou	145.72
Shanxi[2]	311.89	Gansu	177.41
Xinjiang	223.27		

Notes.[1] the capital is Taiyuan City; [2] the capital is Xi'an City.

Table 8. The suitable use amount of NPK for main food crops in China (1981-1983).

Item	Rice	Wheat	Maize
N (kg/ha)	108.3	104.9	108.4
P_2O_5 (kg/ha)	36.8	66.3	68.3
K_2O (kg/ha)	37.9	0	0
Total (kg/ha)	183	171.2	176.7

Note: Data from the reference [15].

Table 9. The production of fertilizer in different households in the double cropping of rice region (kg/ha).

Yield Level	Actual Yield	Nitrogen Rate	Phosphorous use Rate	Potash Rate	N : P : K	Household %
<6750	5693.7	205.9	94.7	165.7	1 : 0.46 : 0.80	37.61
6751-9000	7474.1	191.2	90.5	140.0	1 : 0.47 : 0.73	53.85
>9001	10429	226.5	67.6	164.5	1 : 0.30 : 0.73	8.54

Table 10. The production of fertilizer in different households in the double cropping of winter wheat-summer corn region (kg/ha).

Yield Level	Actual Yield	Nitrogen Rate	Phosphorous Rate	Potash Rate	N : P : K	Household %
<11250	10346.3	499.3	219.8	105.9	1 : 0.44 : 0.21	26.7
11251-13500	12708.5	593.7	246.0	141.5	1 : 0.41 : 0.24	56.7
>13501	14118.0	589.8	235.5	137.1	1 : 0.40 : 0.23	16.6

efficiency was 26 % and 38%, respectively, while the nitrogen loss could reach from 38 % to 51%.

During corn production, if the nitrogen use efficiency was the maximum, the nitrogen fertilizer use times should be increased, and the amount of application times should be decreased; at the same time, the irrigation times should be increased, the growth speed must be promoted, and the amount of nitrogen absorption should be increased.

In short, as long as nitrogen use efficiency is improved, the crop yield should be increased, the nitrogen loss must be reduced, the nitrate accumulation in the environment must be cut down, and resultantly the nitrate pollution could be prevented to some degree.

CONCLUSION

The nitrate pollution of underground water is a hot topic worldwide. However, China being the largest population size in the world, is facing serious issues in terms of food security problem that is brought to focus worldwide through reserach. The total yield of food grain has increased since 2004, and in this connection, the multiple cropping of winter wheat-summer corn, winter wheat-rice, and double cropping rice play important roles. Besides, the chemical fertilizers have contributed invaluably. With the increased chemical fertilizer application gradually or even overload in some regions of China, the nitrate level of underground water raised or even went over the standard level of WHO. It gave rise to the nitrate pollution of the water body.

The amount of chemical fertilizer application at household, farmland and county levels was obtained. Careful study data came from three levels (county level, household level, and farmland level), three counties (Yujiang county, Xinxiang county, and Jing county), and three models of multiple cropping (double cropping rice, Winter wheat- rice, and winter wheat-summer corn). The results showed that the chemical fertilizer played an important role in increasing crop yields. There was difference between counties and households in that the amount of fertilizer application was gradually increased. The nitrate rate of underground water was slowly increased, but it did not rise over the standard of WHO. Under the multiple cropping of winter wheat-summer corn, the nitrate level of irrigation well water had raised year after year since 1991.

In order to avoid the nitrate pollution of underground water, some countermeasures should be taken, such as: increasing the fertilizer use efficiency by taking agronomic measures; the fertilizer use efficiency increases to some extent on the basis of the reasonable ratio of NPK; according to the local conditions, a reasonable allocation and application of fertilizer, especially nitrogen fertilizer that is one of the limited agro-resources in China; and depending on the nature of different crop varieties demand different fertilizer types.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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