Research Article

Received: 3 November 2010 Revised: 15 August 2011 Accepted: 22 September 2011 Published online in Wiley Online Library:

(wileyonlinelibrary.com) DOI 10.1002/jsfa.4725

Recent trends of nitrogen flow of typical agro-ecosystems in China – major problems and potential solutions

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Abstract

BACKGROUND: To diagnose problems that threaten regional sustainability and to devise appropriate treatment measures in China's agro-ecosystems, a study was carried out to quantify the nitrogen (N) flow in China's typical agro-ecosystems and develop potential solutions to the increasing environmental N load.

RESULTS: The analysis showed that owing to human activity in the agro-ecosystems of Changjiang River Basin the mean total input of anthropogenic reactive N (i.e. chemical fertiliser, atmospheric deposition and bio-N fixation) increased from 4.41×10^9 kg-N in 1980 to 7.61×10^9 kg-N in 1990 and then to 1.43×10^{10} kg-N in 2000, with chemical fertiliser N being the largest contributor to N load. Field investigation further showed that changes in human behaviour and rural urbanisation have caused rural communities to become more dependent on chemical fertilisers. In rural regions, around 4.17 kg-N of per capita annual potential N load as excrement was returned to farmlands and 1.38 kg-N directly discharged into river systems, while in urbanised regions, around 1.00 kg-N of per capita annual potential N load as excrement was returned to farmlands and 5.62 kg-N discharged into river systems in urban areas.

CONCLUSION: The findings of the study suggest that human activities have significantly altered the N cycle in agro-ecosystems of China. With high population density and scarce per capita water resources, non-point source pollution from agro-ecosystems continues to put pressure on aquatic ecosystems. Increasing the rate of organic matter recycling and fertiliser efficiency with limited reliance on chemical fertilisers might yield tremendous environmental benefits.

Keywords: agro-ecosystem; nitrogen flow; field investigation; human activity; nitrogen use efficiency

INTRODUCTION

Human activities have caused substantial increases in the amounts of anthropogenic reactive nitrogen (N) in environmental reservoirs, resulting in severe distortions in the natural N cycle of the Earth.[1] The biospheric N boundary has been transgressed beyond the 3.5×10^{10} kg-N safe limit as human activity currently releases some 1.21×10^{11} kg-N into the environment, which is more than three times the safe threshold.[2] The highest N use was once limited to Europe and North America, but the development of new economies and changes in agricultural trends have shifted high N uses to Asia and Latin America.[3] In fact, at present, China has the highest fertiliser utilisation in the world.[4]

The FAO's 2006 statistical data[4] show that arable lands in rural areas of China account for only 7% of the world total. China's arable lands, however, not only account for about 33% of chemical fertilisers used in the world but also support 20% of the world population. This intensive chemical fertiliser application leads to massive amounts of waste in air, water and soil systems, with a highly negative environmental impact. Furthermore, China's farmlands produce 50 million tons of pork per annum, accounting for 50% of the world total. Also, because

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wastewater treatment facilities on China's breeding farms are inadequate, the chemical oxygen demand (COD) of discharge waters from livestock facilities is almost equal to that of discharge waters from industrial facilities in China.[5] Moreover, people's consumption pattern/diet in China has changed drastically with rapid economic growth in recent years. The diet system is shifting from a traditional grain-based diet to a meat-based diet more akin to that in developed countries.[6] Increasing animal protein intake increases the amount of N in human excrement. Hence human excrement and other domestic grey water discharge into water bodies is increasing with the availability of flush toilets and sewerage systems.[6] Also, an insufficiency of septic tanks and sewage systems means that most domestic wastewater is discharged untreated into rivers and lakes.[7] Such problems are not only limited to China but also prevail globally. High proliferation of blue/green algae in lakes and dams and frequent coastal red tides lead to severe health and environmental issues.[8,9] To quantitatively evaluate the impact of human activities on the environment, it is important to understand real time changes in China's farmlands. Analysing the changes in human activities not only clarifies the related environmental problems but also facilitates the development of sustainable on-site countermeasures.

Previous studies have investigated N flow in different agro-regions of Changjiang River Basin using a county-level agro-statistical database.[10,11] Liu *et al.*[6] also investigated N flow pertaining to human food consumption and lifestyle (i.e. daily life activities related to diet intake, waste disposal and farming). Liu *et al.*[12] took the study further by quantitatively analysing and comparing representative regions for the impact of human behavioural changes on N flow using integrated statistical and survey data. The present study adds new results to the previous findings with the overall aim of pinpointing the main issues of N flow in China's agro-ecosystems. The study focuses on N flow changes in farmlands and suggests potential solutions to reducing the reactive N load and maintaining a sustainable/balanced N flow in China's agro-ecosystems. As the N problem is not unique to China, the proposed solutions in this study could be applicable to other regions of the world.

MATERIALS AND METHOD

We used data from 801 counties in Changjiang River Basin to develop sufficient insight into not only spatiotemporal changes in farmland N budget (including N source, e.g. atmospheric wet/dry deposition, chemical fertiliser N use, N fixation by legume crops, green manure and non-symbiotic crops, N recycling in human/animal excrement, crop residue/manure and N emission from crop residue combustion; N sink, e.g. N in harvested grain/straw biomass, denitrification, volatilisation and N flow into water bodies by leaching/run-off; and soil N storage) but also N use efficiency in the basin.[11] We also used field data from different agro-ecosystems to isolate human activities such as daily diet intake, domestic wastewater discharge route, chemical fertiliser type and application method, human/animal excrement N discharge into soil/water systems and N from agro-by-product utilisation.[6]

Field investigation was first conducted in 2006 in collaboration with the Integrated Environmental Monitoring (IEM) Network of the Asia-Pacific Environmental Innovation Strategy Project (APEIS). This was followed by data collection via questionnaire and/or personal interview in six typical ecosystems – urban areas of Shijiazhuang (SJZ) in Hebei Province and Wuhan (WH) in Hubei Province and urban city/town and rural township/village areas of Fukang (FK) in Xinjiang Uygur Autonomous Region, Yucheng (YC) in Shandong Province, Taihe (TH) in Jiangxi Province and Taoyuan (TY) in Hunan Province – of China (Fig. 1) in April–June 2006. Feedback was obtained from a total of 1650 people: 200 in SJZ, 150 in WH, 100 in urban FK, 100 in rural FK, 150 in urban YC, 200 in rural YC, 120 in urban TH, 180 in rural TH, 250 in urban TY and 200 in rural TY. To further enhance the survey data, the investigation site was expanded to cover Hanjiang River Basin (HJ), an upper reach sub-basin of Changjiang River Basin, in February–April 2008 and to Shanghai (SH) in September–December of 2009. A total of 800 (350 in urban and 450 in rural areas of HJ) and 450 (300 in urban and 150 in rural areas of SH) people were interviewed (Fig. 1).

The questionnaire comprised four main parts. The first part contained basic information about the respondents, including sex, age, height, weight, occupation, income, registration type, educational level and intensity of daily activities. The second part

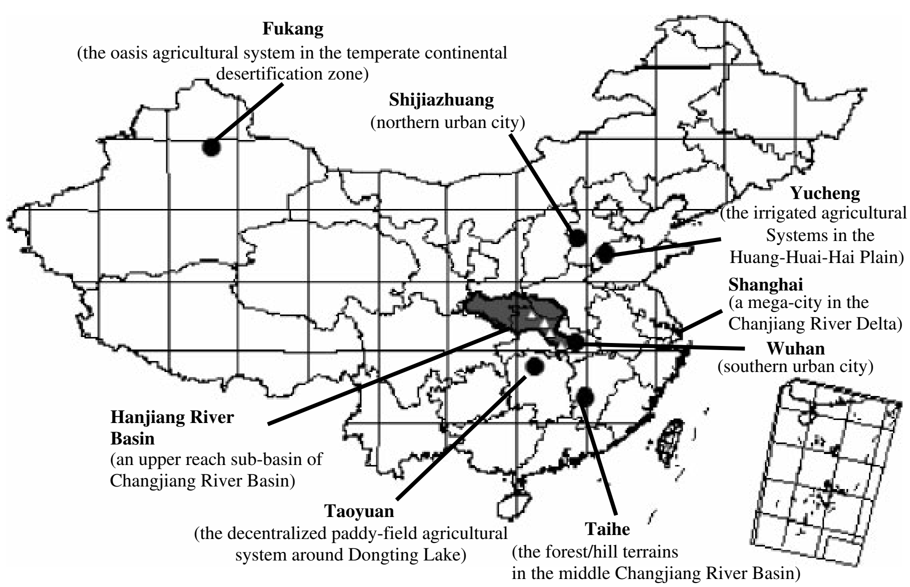

Figure 1. Locations of investigation sites in China.

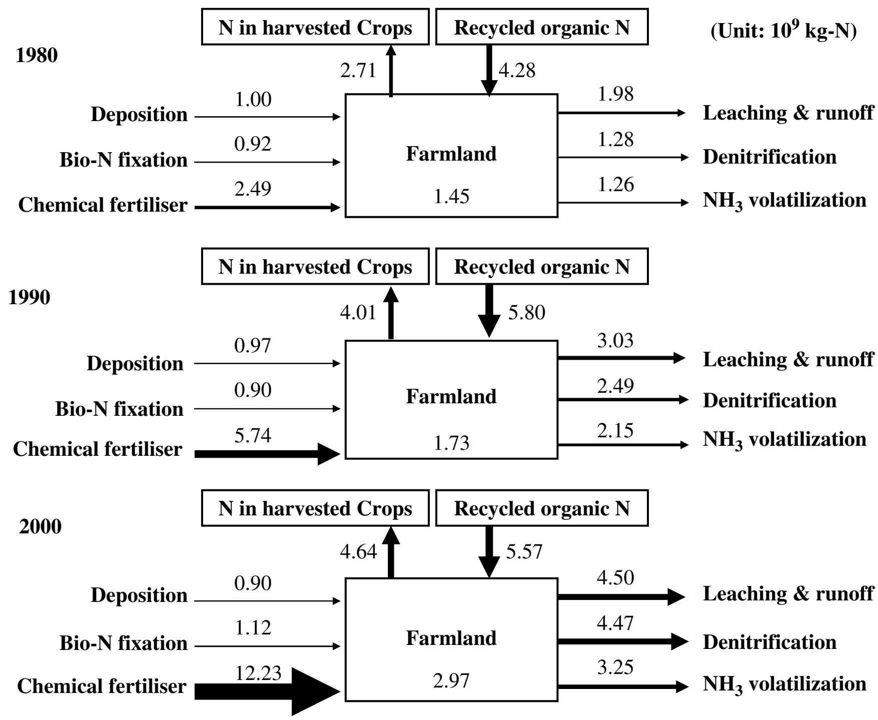

Figure 2. N budget in farmlands of Changjiang River Basin.

included the current state and trend of dietary lifestyle. Here food products were categorised into 47 items in nine groups in accordance with the China Food Composition database.[13,14] The respondents filled in forms based on what and how much was eaten in the last 24 h as breakfast, lunch, dinner and anything in between these main meals. The third part consisted of questions about human waste disposal, including sewage situations, home toilet specifications, discharge routes and user satisfaction. The fourth section comprised questions relating to actual farming methods implemented in the region, i.e. application rates/methods of various chemical fertilisers and recycling of agro-livestock excreta.

RESULTS AND DISCUSSION

Trends in farmland N budget and fertiliser use efficiency

The trend in farmland N budget in Changjiang River Basin for 1980–2000 is shown in Fig. 2. The estimated anthropogenic new reactive N (wet/dry deposition, biological N fixation and chemical fertiliser) input is 1.43×10^{10} kg-N in 2000, which is 1.9 times that in 1990 and 3.2 times that in 1980. Recycled N (from animal excrement, rural human excrement, crop residue, irrigation and seeds) increases slightly from 4.28×10^9 kg-N (1.50×10^9 kg-N from animal excrement and 1.63×10^9 kg-N from rural human excrement) in 1980 to 5.80×10^9 kg-N (2.16×10^9 kg-N from animal excrement and 2.03×10^9 kg-N from rural human excrement) in 1990, but because of a declining rural population it decreases slightly to 5.57×10^9 kg-N (2.18×10^9 kg-N from animal excrement and 1.53×10^9 kg-N from rural human excrement) in 2000. Human and animal excrement accounts for 67–73% of total recycled N in the region. Recycled organic N in 1980 is 1.7 times higher than chemical fertiliser N, implying that crop production in the region is mainly supported by recycled organic N. However, released N from chemical fertilisers increases drastically to 1.22×10^{10} kg-N in 2000. This is the equivalent of a fivefold increase over 1980, becoming the largest N contributor in the basin in 2000. On the other hand, harvested crop N (including straw N) is estimated at 2.71×10^9 kg-N in 1980, 4.01×10^9 kg-N in 1990 and 4.64×10^9 kg-N in 2000. This is a 1.71-fold increase in 2000 over the value for 1980. N use efficiency (i.e. the proportion of N input, including anthropogenic new reactive N and recycled organic N, exported via harvested crop N) decreases from 31% in 1980 to 30% in 1990 and then to 23% in 2000 (Fig. 3). The proportion of N in harvested crops to total N input decreased, while that lost by denitrification, volatilisation and riverine N transport and the proportion stored in soil increased 2.5-fold between 1980 and 2000 (Fig. 2). Table 1 details the prevailing agricultural conditions for 1980, 1990 and 2000 with regard to the parameter factors of cultivated land area, cropped land area, multi-cropping index (cropped land area/cultivated land area), crop yield (including straw) and fertiliser application rate. Whereas cultivated land area decreases, cropped land area increases. This implies that agricultural lands in Changjiang River Basin intensified substantially, especially in 1990–2000. Compared with the world's average N fertiliser application rate (FAOSTAT, 102–117 kg-N ha^{-1}), N fertiliser application rate (225 kg-N ha^{-1} in 2000) is almost two-times higher in Changjiang River Basin. Crop yield increases from 82 kg-N ha^{-1} of cropped land area in 1980 to 117 kg-N ha^{-1} of cropped land area in 1990, but it decreases to 86 kg-N ha^{-1} of cropped land area in 2000. In terms of N, this trend implies that crop production increases by 35 kg-N ha^{-1} of cropped land area with the addition of 92 kg-N ha^{-1} of chemical fertiliser in 1980–1990. Contrarily, crop production decreases by 31 kg-N ha^{-1} of cropped land area for every 58 kg-N ha^{-1} addition of chemical fertiliser in 1990–2000. The drop in crop production could be caused by (1) decreasing fertiliser use efficiency due to increasing chemical fertiliser application (this is simply the law of diminishing returns, which states that, holding all other inputs constant, the marginal product of each unit of input declines as the

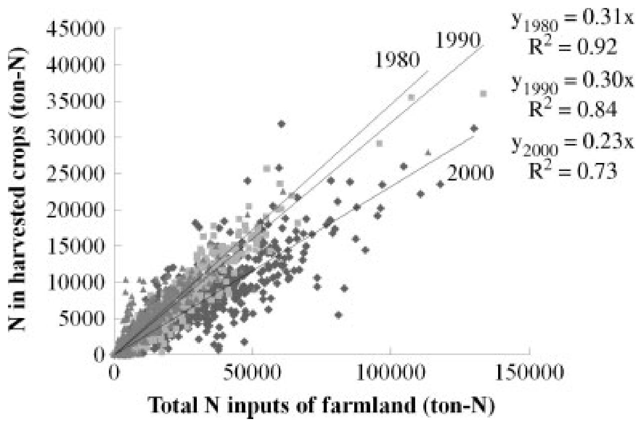

Figure 3. Relationship between total farmland N input and harvested crop N.

Table 1. Variations in studied parameters during 1980–2000

Parameter	1980	1990	2000
Cultivated land (10^6 ha)[a]	26.6	25.5	24.0
Cropped land (10^6 ha)[a]	33.2	34.3	54.2
Multi-cropping index (%)	125	135	226
Crop yield (kg-N ha^{-1} of cropped land area)[a]	82	117	86
N fertiliser (kg-N ha^{-1} of cropped land area)[a]	75	167	225

[a] Data from 1981, 1991 and 2001 China Rural Statistics Yearbooks.[15–17]

amount of that input increases), (2) effective utilisation of recycled organic fertiliser in the agro-ecosystems in 1980, as against limited utilisation in 2000, and (3) decreasing fertiliser use efficiency due to multiple cropping and intensive farming.

The high fertiliser application rate and low N use efficiency are the most important factors of environmental degradation (e.g. eutrophication, global warming gas emission, etc.) in the study area. Note that the ratios of N discharge in soils or rivers from waste and livestock excreta are set constant in the above estimates at 40% of rural human excrement for recycled N in soils and 60% of rural human excrement for discharged N to surface waters and at 40% of cattle/sheep excrement and 100% of pig/poultry excrement for recycled N in farmlands.

Human N intake via diet and discharge route of human waste

Based on field investigations, per capita daily protein intake by food group in the region is detailed in Table 2. Per capita average daily protein intake is 113.4 g in urban areas and 95.1 g in rural areas, and the difference between the two is significant at $P < 0.05$. A difference in diet in terms of economic status determines the differences in prevailing characteristics/habits among the ecosystems. For instance, Fukang is known for sheep pasture, where economically developed urban dwellers consume more meat protein (especially mutton and dairy products such as cheese) than those in other regions of the country. Shanghai is known for freshwater/seawater farming, and Shanghai dwellers consume more fish protein than those in other regions. One possible reason for high fish consumption in Taihe is proximity to the dam, where extensive fish farming ensures ready availability and affordability. The insignificant difference between urban and rural areas of Yucheng and Taoyuan is because the region is primarily an agricultural county. On average, urban dwellers consume more meat, egg, fish, milk and legume products and fewer grain, vegetable and fruit products than rural dwellers.

There is a significant difference between urban and rural regions in terms of potential N load from human waste. While the rate of returned human waste to soils via septic tank, manure store and biogas plant decreases, that discharged in rivers via drainage and sewage increases (Fig. 4). Assuming that N intake is proportional to N content in adult excrement, per capita annual N discharge into the environment is estimated and detailed in Table 3. Per capita potential annual N load in human waste that is returned

Table 2. Daily amount of protein intake (g day^{-1} per person) by food group at investigation site

Location/type		Crop[a]	Meat[a]	Egg[a]	Fish[a]	Legume[a]	Milk[a]	Tuber/starch[a]	Vegetable/fruit[a]	Others[a]	Total[a]	Meat-based[c] (%)
SJZ	Urban	34.7	28.7	6.7	12.3	11.8	6.8	1.3	5.4	8.7	116.5	47
FK[b]	Urban	39.4	29.2	7.8	11.2	12.7	7.9	1.9	3.1	8.7	121.8	46
	Rural	39.5	16.4	8.1	4.8	15.2	2.5	2.3	2.6	6.0	97.4	33
YC	Urban	44.5	28.6	6.5	10.1	8.1	4.0	0.7	3.4	6.5	111.6	44
	Rural	52.6	19.0	6.8	4.1	12.4	1.0	0.6	5.5	3.9	106.1	29
WH	Urban	25.1	22.2	7.6	13.0	19.2	6.8	1.4	2.8	10.6	108.6	46
TH[b]	Urban	33.4	27.2	5.5	14.9	14.4	2.4	0.5	5.4	2.8	106.5	47
	Rural	26.3	23.0	6.3	18.3	9.5	0.1	0.5	6.6	5.9	96.3	49
TY	Urban	30.0	27.2	6.2	11.9	15.8	4.4	1.1	4.6	7.2	108.3	46
	Rural	28.3	31.1	6.7	12.5	10.0	1.7	0.8	4.6	7.7	103.3	50
HJ[b]	Urban	29.3	24.7	13.5	17.8	17.5	2.3	1.3	3.6	7.0	117.0	50
	Rural	33.1	13.4	6.8	8.5	12.5	0.7	0.8	3.4	3.8	83.2	35
SH[b]	Urban	25.4	29.8	9.6	23.0	12.1	5.6	0.8	3.7	6.7	116.8	58
	Rural	26.6	15.5	5.0	15.9	14.4	0.9	0.3	3.6	1.8	84.1	44
Total[b]	Urban	32.7	27.2	7.9	14.3	14.0	5.0	1.1	4.0	7.3	113.4	48
	Rural	34.4	19.7	6.6	10.7	12.3	1.1	0.9	4.4	4.8	95.1	40

[a] Difference in per capita daily amount of protein intake by food group significant at $P \leq 0.05$ (Kruskal–Wallis test) among sites.
[b] Difference in per capita total protein intake per day significant at $P \leq 0.05$ (Mann–Whitney test) between urban and rural residents.
[c] Percentage protein intake from meat-based food (meat, egg, fish, milk) in total ingested protein.

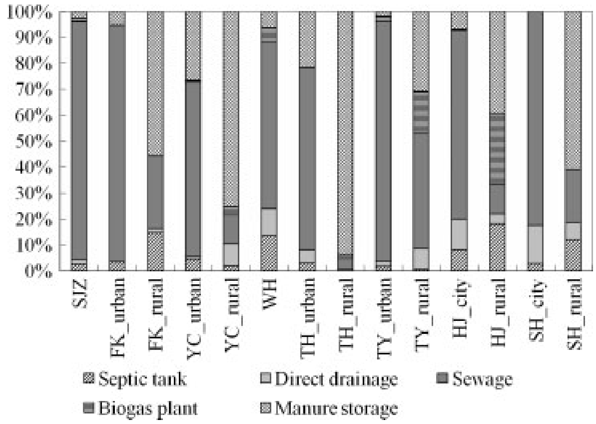

Figure 4. Discharge routes of human waste.

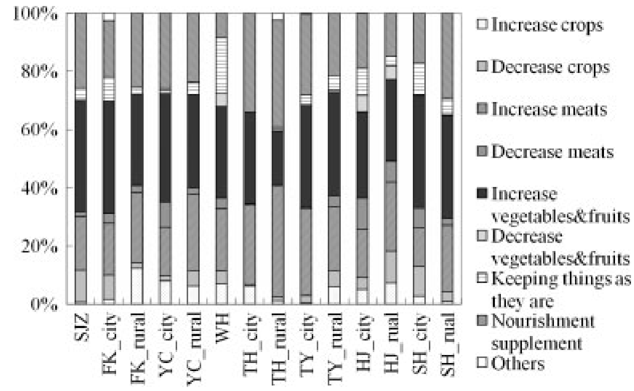

Figure 5. Future consumption trend. Note that 100% here represents total choices available and not total number of respondents.

to farmland in urban areas is around 1.00 kg-N, while 5.62 kg-N is discharged into rivers. For rural regions, around 4.17 kg-N is returned to farmland and 1.38 kg-N directly discharged into rivers. The study further shows that even human wastes stored in septic tanks, manure stores and biogas plants (normally considered as organic fertiliser) are gathered in outdoor heaps and therefore hardly recycled as organic fertiliser in farmlands. This is because there exists manpower shortage in rural areas. In recent years, most youngsters have given up farming and left for cities/towns in search of their fortune. Hence only elderly people over 60 years of age live in rural areas, who cannot do heavy-lifting farming jobs. Much labour and manpower are needed for composting and transporting of excrements on farmlands. Compared with organic fertiliser, chemical fertiliser not only saves labour and manpower but is also very effective.

The future trend in (multi-choice) food consumption in the study area is shown in Fig. 5. There is a preference for high intake of animal-derived foodstuffs, vegetables and fruits. A large proportion of the respondents express a positive attitude towards balanced nutrition; willing to consume nutritional supplements not only in urban areas but in rural areas as well.

Potential river/soil N load via farming method

The investigation shows that the most commonly used chemical fertilisers are urea and mixed fertilisers. Fertiliser diversification occurs widely in agricultural lands with sufficient irrigation systems and in paddy-field plains. Potassium use is relatively low in Yucheng and Shanghai (Fig. 6(a)). In the irrigated agro-systems of Yucheng, fertiliser application is mainly by fertigation because of the ease of adding chemical fertiliser to irrigation water when necessary. Whole-layer application is very common in (the hilly areas of) Taihe because it is reported to prevent N loss via soil erosion. Surface application is common in Shanghai as it highly labour-saving (Fig. 6(b)). In the irrigated agro-systems of Yucheng, over 75% of agro-by-products such as wheat straw are recycled into livestock feed. Almost 80% of agro-by-products are recycled as cooking fuel in Shanghai rural areas. In other regions, most of the agro-by-products such as straw are generally burned or mixed with base fertiliser and returned to the soil (Fig. 6(c)). In most instances, livestock excreta are reduced over time in

Table 3. Potential environmental N load originating from human waste

Location/type		Human waste released to environment (kg-N year^{-1} per person)	Rate (%)		Amount (kg-N year^{-1} per person)	
			Returned to soil	Discharged in rivers/pipes	Returned to soil	Discharged in rivers/pipes
SJZ	Urban	6.80	6	94	0.44	6.36
FK	Urban	7.11	9	91	0.62	6.49
	Rural	5.69	70	30	4.01	1.68
YC	Urban	6.52	32	68	2.09	4.43
	Rural	6.20	80	20	4.97	1.22
WH	Urban	6.34	25	75	1.59	4.76
TH	Urban	6.22	24	76	1.52	4.70
	Rural	5.63	95	5	5.35	0.27
TY	Urban	6.32	6	94	0.35	5.97
	Rural	6.03	47	53	2.85	3.18
HJ	Urban	6.83	15	85	1.02	5.81
	Rural	4.86	85	15	4.13	0.73
SH	Urban	6.82	3	97	0.20	6.62
	Rural	4.91	73	27	3.58	1.33
Total	Urban	6.62	15	85	1.00	5.62
	Rural	5.55	75	25	4.17	1.38

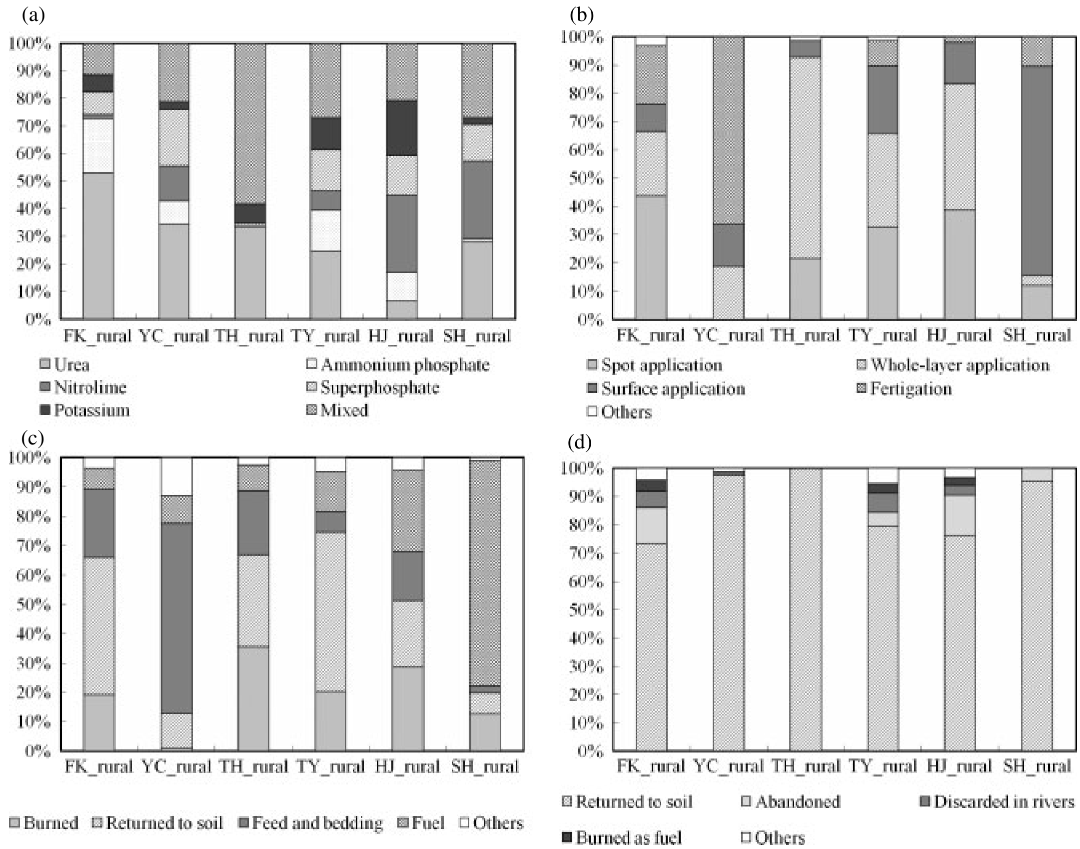

Figure 6. Farming methods: (a) chemical fertiliser type; (b) chemical fertiliser application method; (c) agro-by-product utilisation; (d) livestock excreta utilisation.

pastures/farmlands in the case of traditional small-scale household livestock breeding (Fig. 6(d)). Although farmers have raised three to five pigs per household in the past, such practice is declining with time. This is not only because pig raising is difficult in terms of technical knowhow, manpower and time, but also because of high instability of meat market prices, cost of processed feed and availability of low-priced alternative meat. On the other hand, the number of large-scale livestock breeding centres introduced via external financing is steadily increasing. This study, however, did not identify waste discharge routes of these externally financed livestock breeding centres as they were not included in the field investigation.

Potential solutions for decreasing N loads and sustained N balance

As demonstrated in this study, the changes in human activities due to economic growth and urbanisation are as follows: (1) increased consumption of animal-based products, leading to increasing demand for such products over crop-based products; (2) increasing use of flush toilets, reducing human/animal waste recycling in agricultural lands; (3) increasing dependence of rural communities on chemical fertilisers; (4) functional shifts in human/animal excrement from soil nutrient to environmental load; and (5) increasing environmental N load from both the surplus application of chemical fertilisers and the abandoned human/animal excrement. Urbanisation of rural areas is expected to accelerate further. According to the Prime Minister Wen Jiabao, the strategy of constructing socialist new farms is steadily promoted and emphasised in the 2006 report of the government activity. In China's rural region with 800 million people, finding better ways of producing, consuming and delivering N without further environmental stress constitutes a tremendous challenge.

In 2008, China's central government released the 'mid/long-term plan for ensured food security in the country'. The plan target is to produce over 500 billion kg of grain by 2010, 540 billion kg by 2020 and 640–702 billion kg by 2030.[18] In China (where 33% of the world's chemical fertiliser is consumed by 20% of the world population) it is important to improve fertiliser use efficiency for sustainable increase in crop production. Finding ways of increasing crop N use efficiency is also critical for decreasing N loss to the environment. With highly intensified cropping systems in China, further improvements in fertiliser use efficiency remain a daunting challenge.[19] Nevertheless, advances in fertilisation-related sciences and technologies raise the possibility of meeting this challenge. For example, Ju *et al.*[20] reported that current agricultural N practice with 550–600 kg-N ha^{-1} $year^{-1}$ cannot significantly increase crop yield. It could, however, increase N losses to the environment twofold. Hence knowledge-based optimum N fertilisation could save 30–60% of N fertiliser.[20]

Developing an efficient soil/fertiliser strategy management system is also critical. For example, the law of diminishing returns necessitates the development of different fertilisation strategies that reflect the nutrient state of soils. This implies that nutrient-deficient soils require high fertilisation to build soil fertility and increase yield, nutrient-sufficient soils need limited fertilisation to maintain soil fertility, and nutrient-abundant soils need cultivation to deplete soil nutrient. Improper use of fertilisers is another factor for low N efficiency in China. In extreme cases, farmers continue intensive fertilisation to further increase productivity even under sufficiently fertile soil conditions. NPK balance is also very important for crop growth – a factor that farmers still remain unfamiliar with. The establishment of information systems to strengthen technological transfer to farmers is equally an important factor.

Next to chemical fertilisation, N from human waste is the second largest source of increasing N load from farmlands to the environment (Fig. 2). China plans to enlarge facilities for urban pipe water and sewage treatment systems. With the proliferation of flush toilets, the rate of human excreta returned to soils is decreasing, as most of such wastes are discharged via pipe systems. Because N removal rate by sewage treatment systems is less than 20% in China, most of the N in human waste is discharged into water bodies. This causes widespread water pollution problems in the country. Over a period of 1 year the average person disposes through pipe water and sewage treatment systems 400 L of harmless urine (containing 4 kg-N and 0.4 kg-P, directly usable as farmland fertiliser) and 50 L of harmless faeces flushed by 1.5×10^4 L of pure water.[21] Removal of N and P in wastewaters requires the construction of costly sewage treatment plants at the end of the pipe systems. This implies that dealing with only 50 L of harmless faeces wastes not only 300 times that volume of pure water but also leads to losing valuable urine fertiliser. In European counties, ecological sanitation systems are prevalent, which are clean and economical. Urine and compost can also be used as fertiliser, limiting chemical fertiliser application. Water issues (e.g. shortages of water resources and drinking water in terms of quantity and quality and degeneration of water environments) are closely linked to organic waste disposal. China faces myriad hydrological issues (including a lack of aquatic resources, quantitative/qualitative issues of drinking water and deterioration of water environment) that are intricately related with excrement and organic waste problems. There is therefore a dire need to construct systems that support waste circulation and recycling needs of China.

Environmental N load originating from livestock excreta is also a serious problem. While small-scale livestock breeding is on the decline in the study area, intensive large-scale livestock breeding is increasing. This trend is spurred by huge economic benefits and manpower shortage in rural areas. Most of the livestock breeding centres are, however, not equipped with wastewater processing systems, raising concerns about possible excessive livestock excreta pollution of water systems. The increased N load from large-scale livestock breeding without wastewater treatments is therefore a potential environmental problem. Improved animal management strategies and methods/technologies of livestock excreta recycling are therefore needed for reducing the N load to the environment.

Recycling-based agriculture has gradually taken root in Japan in recent years. For instance, technology is now available for converting all sorts of organic matter (excrement, straw, waste, etc.) to organic carbon fertiliser, which drastically improves soil conditions. As shown in Fig. 1 and Table 1, efficiently reusing recycled N could cut down chemical fertiliser application by almost half. Relying entirely on pipe-borne systems could spur environmental N load from both chemical fertilisers and recycled N.

Given the complexities of N use, its environmental mobility and differences among regions, no single and definite strategy suffices. This is especially true for China, a large country with diverse agro-ecosystems and stages of economic development. With the notion of 'creating a harmonious society', the government of the People's Republic of China has proposed large-scale environmental technologies and improvement projects. It is important to incorporate suitable N management systems within these strategies/projects.

CONCLUSIONS

The findings of this study suggest that human activities have significantly altered the N cycle in agro-ecosystems of China. With high population density and scarce per capita water resources, non-point source pollution from agro-ecosystems continues to put pressure on water environment. Increasing the rate of organic matter recycling and fertiliser efficiency with limited reliance on chemical fertilisers might yield tremendous environmental benefits. Thus technology, management, education, etc. are required for increasing fertiliser use efficiency and the rate of organic matter recycling. This study provides not only a baseline N cycle but also a useful case-study for sustainable development and management of rural communities.

The present study reveals new issues that are not supported by the current designed questionnaire/personal interview but will be examined in future studies. For instance, besides the traditional small-scale household livestock breeding, waste discharge of the externally financed livestock breeding centres is another potential factor of increasing N load in the region. This requires adequate redressing for sustainable environmental management in the study area. Detailed data collection is also need to more adequately isolate regional differences. More specifically, a timeline investigation with fixed respondents could be necessary in determining the dynamics of human behaviour in the region. Hence studies will continue in basic and clinical environmental research with the aim of not only diagnosing problems that threaten the sustainability of the relationship between human society and the natural world but also developing appropriate prevention/treatment measures and predicting the avoidance of potential side effects of such treatment measures.[22]

ACKNOWLEDGEMENTS

This study was supported by the Nagoya University Global COE (Center of Excellence) programme 'From Earth System Science to Basic and Clinical Environmental Studies' (FY2009-2013), the 'Development of Environmental Management Techniques over the Yangtze River Delta for Conservation of the Environment of East China Sea' (2009–2011) programme sponsored by the Ministry of Environment, Japan, and the international collaborative project supported by the Ministry of Science and Technology, China (2009DFA21690).

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