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Identification of anthropogenic parameters for a regional nitrogen balance model via field investigation of six ecosystems in China

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Abstract To evaluate the impact of human behavior (with regard food consumption, waste disposal and farming method) on nitrogen flow, a field investigation was conducted in six typical ecosystems in China. A number of parameters for regional nitrogen balance models were identified during the investigation. The results show that the average per-capita daily protein intake is 107 g. While there is an insignificant difference in total protein intake among the different ecosystems, protein intake from all food groups, except for eggs, is significantly different ($P \leq 0.05$). Differences in diet, along with those in socio-economic conditions, reflect differences in the characteristics of the ecosystems. Regarding per-capita annual potential nitrogen loading from human excrement, a considerable difference exists between the urban rich and the rural poor. In urban areas, approximately 1.02 kg N is returned to farmlands and 5.49 kg N is directly discharged into rivers. In rural regions, on the other hand, approximately 4.33 kg N is returned to farmlands and 1.60 kg N is directly discharged into rivers. Furthermore, urea and mixed fertilizers constitute the most common chemical fertilizers in the study area. Fertilizer diversification is practiced in a range of agricultural lands, paddy-fields and irrigated plains. In the oasis and paddy-field agricultural systems, many of the agricultural by-products (e.g., straw) are burned or mixed with base-fertilizers and plowed into the soil. In irrigated agricultural systems, over 70% of agricultural by-products are recycled as livestock feed. In most instances, livestock excrement is directly reduced in the pasturelands or reused in the fields as manure. Occasionally, as in the case of large-scale breeding, excrements are usually abandoned.

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Introduction

Nitrogen (N) is a key indicator of the human impact on the environment, which SCOPE (the Scientific Committee on Problems of the Environment) has identified as a major emerging environmental issue of the twenty-first century (Munn et al. 1999). Human activity has greatly altered the N cycle, accelerating N fixation in soils and delivery to surface water bodies (Galloway et al. 1995, 1996, 2004; Howarth et al. 1996, 2002; Galloway 2000; Galloway and Cowling 2002; Van Breemen et al. 2002; Boyer et al. 2002; Zheng et al. 2002; Yan et al. 2003).

With rapid economic growth and industrial and agricultural development, the diet of the Chinese population has shifted from the traditional grain-based to the meat-oriented diet prevalent in developed countries. Also, agricultural practices have accordingly shifted from extensive to intensive farming. The changing pattern of lifestyle and farming substantially impacts the balance of material cycles including carbon and nitrogen, which may in turn variously impact environmental resources.

A number of studies has focused on he different aspects of N budget in China. Xing and Zhu (2002) addressed nitrogen input, output and storage in whole watersheds and three major river valleys in China. Xing and Yan (1999) estimated direct nitrous oxide emissions and changes in agricultural fields for the period 1949–1995. Xiang et al. (2005) and Liu et al. (2006, 2008a) attempted a county-level study of N budget, and then N change for the period 1980–2000 in the Changjing River basin using agricultural statistical database. Ellis and Wang (1997) and Ellis et al. (2000a, b) characterized farming practices for the last decade in different Chinese villages and noted substantial changes in the fertilizers sources and the fate of waste residues.

Despite these studies, however, nitrogen cycling model parameters that are influenced mainly by human activity (e.g., human dietary nitrogen intake, amount of nitrogen discharged into the soil or rivers through waste, types and application rates of nitrogen chemical fertilizers in farming, and discharge routes for nitrogen in agricultural by-products and livestock excreta) have not been quantified, especially at regional scale. At present, average constant values are often used for these parameters making it almost impossible to realistically reflect the effect of human behavior on regional nitrogen flow. Liu et al. (2008b) conducted a pilot survey in two representative counties (Taoyuan and Taihe) in Changjiang River Basin based on daily human activity and used the data to quantitatively evaluate the impact of human behavior (food consumption and human excrement disposal) on nitrogen flow in China. However, both counties used in the study are in the middle and lower plains of Changjiang River Basin—a flourishing rice production region. Thus the survey cannot be considered adequately reflective of the realities of the vast irrigated agricultural fields in North China, the inland oases of Northwestern China and the urban regions; which are actually experiencing the strongest economic growth.

Besides the dietary habits of the people, farming methods (e.g., the application rate/method of different chemical fertilizers and the recycling of by-products and livestock excrement) contribute significantly to environmental nitrogen loading in agricultural ecosystems. Because of information dearth regarding dietary habits and farming methods in different areas of China, the nitrogen flow in existing statistical records can neither be trusted as being regionally representative. The present study therefore attempts to identify, via field investigation of six types of ecosystem in China, anthropogenic parameters for the regional nitrogen balance model depicted in dotted line in Fig. 1. These parameters include human dietary nitrogen intake, nitrogen discharge into the soil or rivers through excrement, types and application rates of nitrogen chemical fertilizers in farming, and discharge pathways of nitrogen in agricultural by-products and livestock excrement.

Methodology

Investigation site and procedure

The field investigation was conducted via tailored questionnaire and interpersonal interview in the

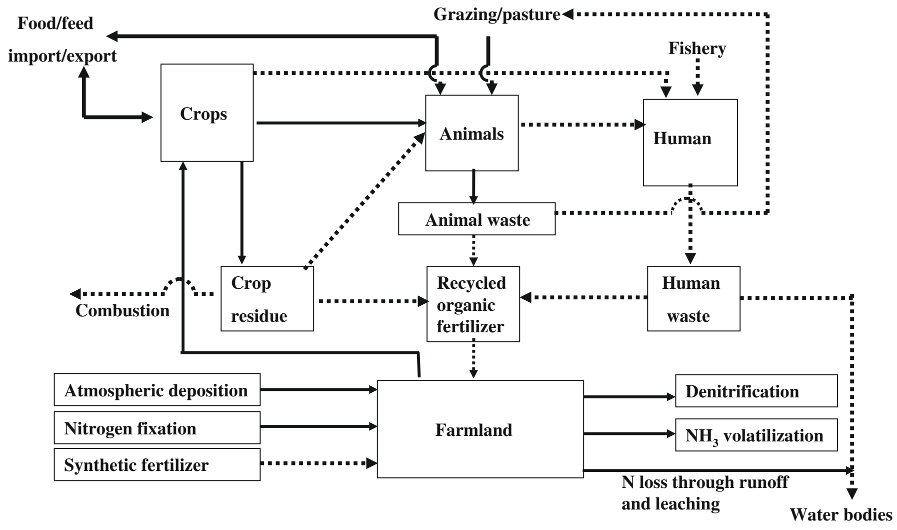

Fig. 1 Regional nitrogen balance model used in this study
⋯⋯▶Flow clarified in this study

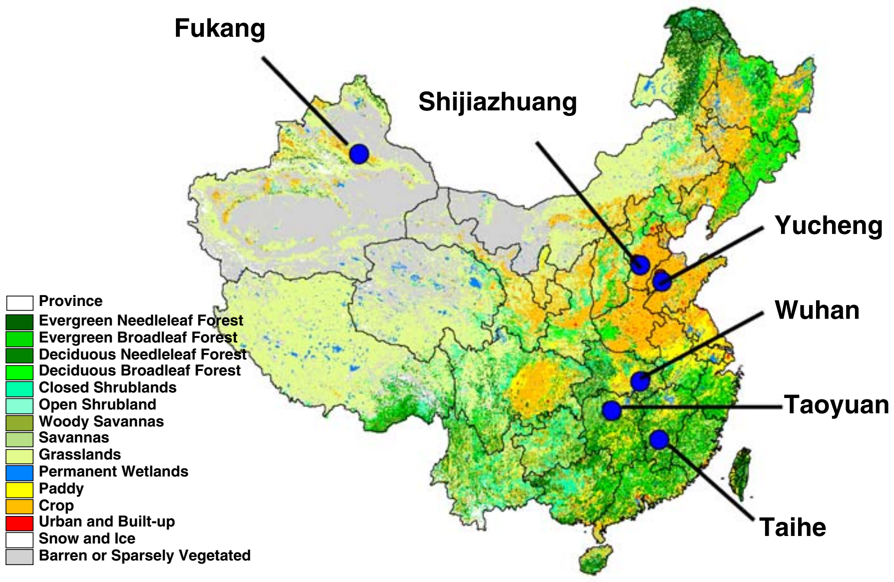

Fig. 2 Investigation sites

urban cities of Shijiazhuang (Hebei Province) and Wuhan (Hubei Province); and one urban (city/town) and rural (village) areas each in Fukang (Xinjiang Uygur Autonomous Region), Yucheng (Shandong Province), Taihe (Jiangxi Province) and Taoyuan (Hunan Province). The survey was conducted in a total of ten settlements in six provinces (Fig. 2) between April and June 2006, and in collaboration with the Integrated Environmental Monitoring (IEM) Network of the Asia-Pacific Environmental Innovation Strategy (APEIS) project. As this study is not a large-scale field investigation given the size of China, the field investigation sites were carefully selected to reflect six typical ecosystems in the country. The six ecosystems include Shijiazhuang (SJZ, the provincial capital of Hebei Province)—which is one of the largest northern cities of Yellow River basin; Wuhan (WH, the provincial capital of Hubei Province)—which is one of the largest southern cities of Changjiang River Basin; Fukang (FK, located in the southernmost end of Jungar Basin, Xinjiang Uygur autonomous region)—which represents the oasis agricultural systems in the temperate continental desertification zone of

Northwest China; Yucheng (YC, located in the lower and middle alluvial plains of Yellow River)—which represents the irrigated agricultural systems in the Huang-Huai-Hai Plain of North China; Taihe (TH, the forest/hill terrains in the middle Changjiang River Basin)—representing the decentralized paddy-field agricultural systems of South China; and Taoyuan (TY, on the outskirts of Dongting Lake in the middle Changjiang River Basin)—representing the centralized paddy-field agricultural systems of South China. Detailed characterization (land-use, climatic condition, cropping system, socio-economic condition, etc.) of the six typical ecosystems is given in Table 1.

A total of 1,650 respondents (200 in Shijiazhuang, 150 in Wuhan, 100 each in urban/rural Fukang, 150 and 200 in urban/rural Yucheng, 120 and 180 in urban/rural Taihe, and 250 and 200 in urban/rural Taoyuan, respectively) participated in the study. The employed sampling method is described in the following steps: In the first step, ten numbers were randomly selected from a random number table. Then the ten numbers corresponding with the streets numbers were identified for the region. Next, a house was selected as the starting point, also using a random number table, and the seniormost occupant of every 5th house interviewed. If, however, we came across ten or more adults in the street from a 5th house to the other, the 10th person in

Table 1 Detailed characterization of the six typical ecosystems

		Shijiazhuang[a]	Fukang[b]	Yucheng[b]	Wuhan[a]	Taihe[b]	Taoyuan[b]
Total area (ha)		45,600	1,173,333	99,243	161,500	266,700	444,771
Land use (percentage)	Forest	–	12	10	–	60	60
	Grasslands	–	66	0	–	15	8
	Paddy field	–	0	0	–	15	15
	Uplands	–	4	53	–	2	4
	Urban	–	1	10	–	1	1
	Waters	–	0	0	–	3	8
	Others	–	17	27	–	4	4
Cultivated land area (ha)		–	52,867	85,536	–	113,697	212,443
Climate type		Warm-temperate semi-humid	Temperate arid	Warm-temperate semi-humid	Subtropical monsoon	Subtropical monsoon	Subtropical monsoon
Average temperature (°C)		13.7	6.1	21	16.4	17.9	16.5
Average precipitation (mm)		569.8	173	610	1,284	1,542	1,448
Soil properties		–	Oasis soil	Alluvial soil, Salty Wet Soil	–	Red soil	Red soil
Population (persons)		2,313,500	158,500	509,300	5,012,200	515,655	973,912
Per capita GDP (yuan/person)		35,333	19,274	15,708	45,541	7,197	7,322
Cropping system (rotations)		–	1	2	–	3	3
Main crops		–	Cotton, wheat, grape, hops flower	Spring wheat-corn	–	Early rice-late rice-rape	Early rice-late rice-rape
Main domestic animals		–	Goat, sheep, cattle	Cattle, pigs, chicken	–	Cattle, pigs, and chicken	Pigs, chicken
Electric power used by agricultural equipment and machinery (kW)		–	116,523	No data	–	61,088	212,477
Amount of multifilm used (*t*)		–	No data	No data	–	31	356

[a] *Data source:* China City statistical yearbook 2007

[b] *Data source:* Statistical data for Fukang, Yucheng, Taihe and Taoyuan in 2006

the street was interviewed instead; eventually skipping the next 5th house. Participation was strictly limited to adults aged 18 and above. Half of the responses were obtained through interpersonal interview conducted by trained field-workers, while the rest were obtained via the tailored questionnaire. In Wuhan, a random sampling was conducted in the neighborhood of Yangtze River Water Resources Protection Science Research Institute—one of the collaborating research institutions for the study.

Content of the questionnaire

The questionnaire was divided into four parts. The first part comprised personal information about the respondents' sex, age, height, weight, occupation, income, registration type, education and daily activity. The second part included the current state and trend of dietary lifestyle. Under this part, food products were categorized into 47 items in nine groups based on China Food Composition Database (Yang et al. 2002; Yang 2004). The respondents were then asked to fill out the form recalling what and how much they ate in the last 24 h as breakfast, lunch and dinner. In addition, questions were asked regarding the change in consumption structure in the last 10 years and the likely future preferences. The third part comprised of questions pertaining to human excrement disposal. This part of the questionnaire included questions about sewage situation, specifications of household toilet, discharge pathway and use satisfaction. The fourth section comprised of questions relating to farming methods implemented in the last 1 year; i.e., the application rates/methods of various chemical fertilizers and the recycling of agricultural by-products and livestock excrement.

The 24-h dietary recall method used in this study is one of the established dietary evaluation methods for determining actual food intake, which is often used in national health and nutrition surveys and in continuous national food consumption and individual food intake research studies in the US (see Briefel 1994; Guenther 1994). This method has several shortcomings; including its dependence on respondents' short-term memory or diets not representative of represents' typical daily intake. However, if the focus of a study is on average values of identified groups, then the 24-h dietary recall method is arguably sufficient (National Research Council 1986). In the current study, the survey method was improved by administering a round-week questionnaire—from Sunday to Saturday, reflecting the different dietary practices within the week. Also, only experienced and trained field-workers were recruited for administering the questionnaire.

Data analysis

Using collected data from the field survey, a database on human behavior and farming method was constructed and analyzed. The analyses included the per-capita daily intake of protein, food consumption trend, potential environmental nitrogen loading from human excrement, rate of recycled nitrogen in agricultural lands, type and ratio of major nitrogen chemical fertilizers, and nitrogen output flow in agricultural by-products and livestock excrement. Based on the calculations from per-capita daily food intake (g) for each region, per-capita protein intake was calculated and protein content in each food product established according to China Food Composition Database (Yang et al. 2002; Yang 2004). Dietary nitrogen intake was estimated by multiplying total dietary protein by 0.16 (the nitrogen content of protein). Nitrogen in human excrement was calculated based on the assumption that the amount of nitrogen consumed is proportional to that discharged in healthy adults under standardized metabolic conditions (Nanzando's Medical Dictionary 2006). We estimated the amount and rate of returned nitrogen to the soil and that discharged into rivers using household toilet type and discharge route data on human excrement. In rural areas, output flows from agricultural by-products and livestock excrement were further estimated using the survey data on agricultural by-product (e.g., straw) and livestock excrement utilization.

Regarding the statistical analysis, tests of normalcy were first conducted on each of the variables of interest including respondents' height, weight, annual per-capita income, and daily per-capita dietary protein intake by food group. For all the variables, $P \leq 0.05$; hence the test suggests normalcy assumption violation. Therefore respondents' age, height, weight, annual household income, annual per-capita income, per-household floor-area, and daily per-capita dietary protein intake by food group were compared among the ecosystems (six provinces) using the Kruskal–Wallis test, and among urban and rural areas using the Mann–Whitney test. Both of these tests are non-parametric.

Results and discussion

Respondent characteristics

The numbers of valid responses are 154 (77%) in Shijiazhuang, 106 (71%) in Wuhan, 63 (63%) in urban Fukang, 75 (75%) in rural Fukang, 126 (84%) in urban Yucheng, 172 (86%) in rural Yucheng, 100 (83%) in urban Taihe, 153 (85%) in rural Taihe, 172 (86%) in urban Taoyuan, and 184 (92%) in rural Taoyuan. The respondent characteristics are summarized in Appendix. A large percent of the male respondents are in the rural areas, possibly because men are likely to respond to surveys as household heads. In terms of age, over half of the respondents are in their thirties and forties; except for Wuhan, where a large portion of the respondents are students with mean age of 26. This is because the sampling was conducted in the neighborhood of the collaborating research institution. There are significant differences between the six typical ecosystems for all variables ($P < 0.05$). In Fukang, Yucheng, Taihe and Taoyuan, significant differences exist between the urban and rural areas ($P < 0.05$) for age, annual household income, household size, per-household floor-area and per-capita annual income. However, the differences for height and weight are insignificant ($P > 0.05$).

It should be noted that per-capita annual intake and discharge of nitrogen may be slightly overestimated owing to the following reasons: the study was designed for adults aged 18 and beyond; high male respondent ratio; high young student ratio in Wuhan; and the survey period (April–June)—which corresponds with the season for farming during which period farmers are busiest, with levels of physical activity and food intake higher than annual.

Identification of nitrogen-flow parameters related to dietary habit

Dietary nitrogen intake by food group

Table 2 shows the daily per-capita dietary protein intake by food group and survey region. On average, respondents consume 107 g of protein per day, with

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

		Crops[b]	Meats[b]	Eggs	Fish[b]	Legumes[b]	Milk[b]	Tubers and starches[b]	Vegetables and fruits[b]	Others[b]	Total
Shijiazhuang		35	29	7	12	12	7	1	5	9	116
Fukang[a]	Urban	39	29	8	11	13	8	2	3	9	122
	Rural	39	16	8	5	15	3	2	3	6	97
	Total	39	22	8	8	14	5	2	3	7	109
Yucheng	Urban	44	29	7	10	8	4	1	3	6	112
	Rural	53	19	7	4	12	1	1	5	4	106
	Total	49	23	7	7	11	2	1	5	5	108
Wuhan		25	22	8	13	19	7	1	3	11	109
Taihe[a]	Urban	33	27	5	15	14	2	1	5	3	106
	Rural	26	23	6	18	10	0	0	7	6	96
	Total	29	25	6	17	11	1	0	6	5	100
Taoyuan	Urban	30	27	6	12	16	4	1	5	7	108
	Rural	28	31	7	13	10	2	1	5	8	103
	Total	29	29	6	12	13	3	1	5	7	106
Total[a]	Urban	34	27	7	12	14	5	1	4	7	111
	Rural	36	24	7	11	11	1	1	5	6	102
	Total	35	26	7	11	13	3	1	5	7	107

[a] With regard to the total per capita protein intake from food per day, a significant difference was found between urban and rural residents ($P \leq 0.05$, Mann–Whitney test)

[b] With regard to the daily per capita amount of protein intake by food group, a significant difference was found among the sites ($P \leq 0.05$, Kruskal–Wallis test)

insignificant differences in total protein intake between the six provinces ($P > 0.05$). Significant differences exist in daily per-capita protein intake between the urban and rural areas in Fukang and Taihe ($P < 0.05$). The differences are, however, insignificant for the urban and rural areas in Yucheng and Taoyuan ($P > 0.05$). With regard protein intake by food group, significant differences are observed between the six provinces for all food groups ($P < 0.05$), except for eggs. These differences likely reflect not only disparities in economic conditions, but also in community characteristics, climate and local culture. For example, Fukang is well known for sheep pasture, and people living in economically developed urban areas consume more meat protein (especially mutton and dairy products e.g., cheese) than those in other regions of the country. One of the possible reasons for the high consumption rate of fish in Taihe is proximity to the dam where extensive fish farming occurs hence ready availability and affordability. There is an insignificant difference between the urban and rural areas in Taoyuan because this region is primarily an agricultural county. In Fukang, Yucheng and Taihe, urban respondents consume more meat, legumes, fish and dairy products, but less grains, vegetables and fruits than rural respondents.

Potential environmental nitrogen loading from human excrement

Based on the assumption that nitrogen intake is proportional to nitrogen content in excrement, we estimated annual per-capita nitrogen discharge into the environment (Table 3). Field data on household toilet type and discharge pathways of human excrement are, respectively summarized in Figs. 3 and 4. Although sewage systems are well developed and flush toilets prevalent in urban areas, many rural households still use “collection pits” and “vault toilets”. The only exception is rural Taoyuan, where sewage systems are relatively well developed and more than half of the households are equipped with flush toilets.

Human excrement stored in “septic tank” and “manure storage” facilities together with residue for “biogas plants” is usually returned to the soil as

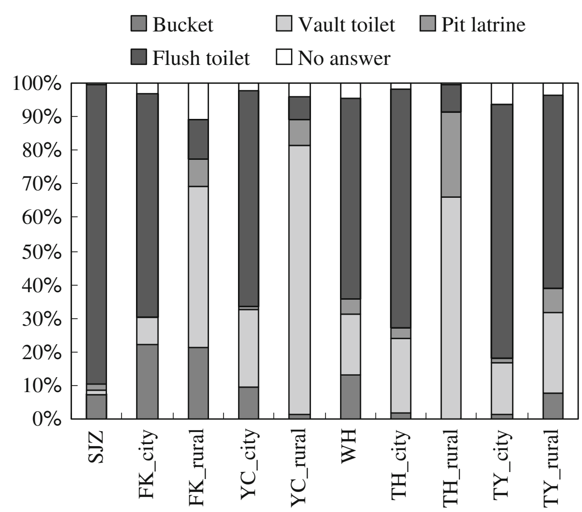

Fig. 3 Type of family toilet

Table 3 Potential environmental nitrogen loading originating from human waste

		Protein intake (g person^{-1} day^{-1})	Human waste released into the environment (kg N person^{-1} day^{-1})	Rate (%)		Amount (kg N person^{-1} day^{-1})	
				Returned to soil	Discharged into rivers	Returned to soil	Discharged into rivers
Shijiazhuang		116.5	6.80	6	94	0.44	6.36
Fukang	Urban	121.8	7.11	9	91	0.62	6.49
	Rural	97.4	5.69	70	30	4.01	1.68
Yucheng	Urban	111.6	6.52	32	68	2.09	4.43
	Rural	106.1	6.20	80	20	4.97	1.22
Wuhan		108.6	6.34	25	75	1.59	4.76
Taihe	Urban	106.5	6.22	24	76	1.52	4.70
	Rural	96.3	5.63	95	5	5.35	0.27
Taoyuan	Urban	108.3	6.32	6	94	0.35	5.97
	Rural	103.3	6.03	47	53	2.85	3.18

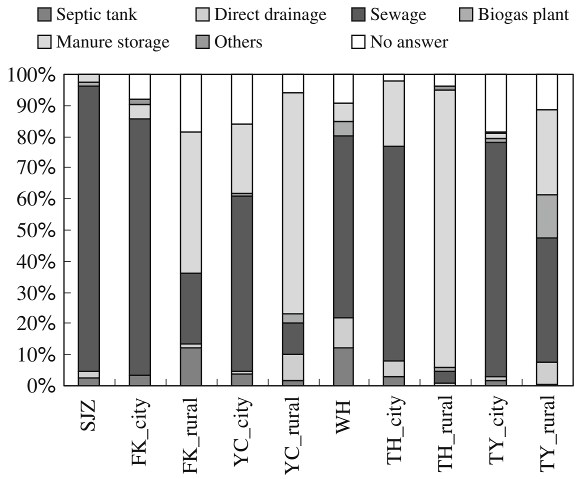

Fig. 4 Discharge route of human waste

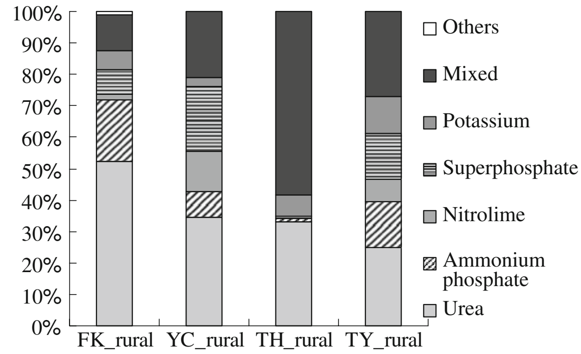

Fig. 5 Type of chemical fertilizer

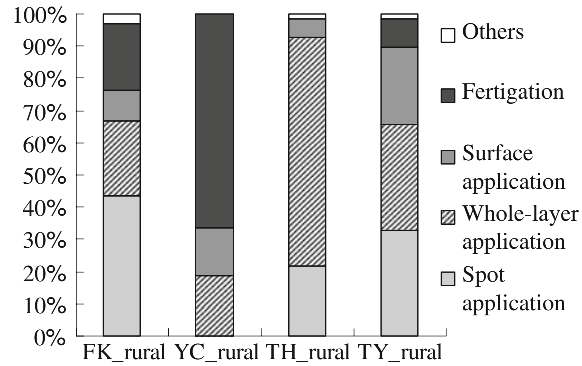

Fig. 6 Method of chemical fertilizer application

fertilizer. Human excrement handled by drainage and sewage systems is usually directly discharged into rivers because of lack of treatment facilities in most rural China. Even in urban areas, most of the nitrogen in human excrement is discharged into rivers because sewage disposal rate is less than 20% and average total nitrogen elimination rate in sewage treatment plants in the country is currently less than 20%. For convenience, we consider human excrement collected in "septic tank", "manure storage", and "biogas plant" residue as "returned to soil" and that directly discharged into drainage and sewage systems as "discharged into river". Responses as "*Others*" or "*No answer*" for discharge pathways are not included in the estimation of per-capita annual nitrogen release into the environment. Table 3 summarizes the estimated amounts and rates of nitrogen returned to soil and those discharged into river. Significant differences exist between urban and rural areas for all the six typical ecosystems. With increasing urbanization, human excrement is more likely discharged into river than returned to soil. For the combined urban and rural samples, the rate of human excrement returned to soil is 16 and 73% while that discharged into river is 84 and 27%, respectively. Per-capita annual potential environmental nitrogen loading originating from human excrement in urban and rural areas is estimated at 1.02 and 4.33 kg N in soils and 5.49 and 1.60 kg N in rivers, respectively. Several studies have adopted 5.0 and 3.3 kg N per person per year, respectively for river nitrogen loading from untreated and treated human excrement (Xiang et al. 2005; Xing and Zhu 2002; Xing and Yan 1999). The large differences in environmental nitrogen loading observed between the urban and rural areas in this study suggest the need for the adoption of different estimates in different regions.

Potential river and soil nitrogen loading from farming method

Type and application method of chemical fertilizer

Field data on the types and application methods of chemical fertilizer in the four rural areas are, respectively summarized in Figs. 5 and 6. In all areas, urea and mixed fertilizers are most dominant. Urea in Fukang and mixed fertilizer in Taihe collectively account for more than half fertilizer utilization in the region. Fertilizer diversification is observed in the large-scale agricultural irrigation systems of Yucheng and in the paddy plain-fields of

Taoyuan. In these regions, urea and mixed fertilizer collectively account for over 50% fertilizer utilization including superphosphate, ammonium phosphate, potassium and nitrolime. Generally, farmers do fertilization twice per rotation: respectively described as base fertilization and auxiliary fertilization. Manure is mostly used as base-fertilizer and is plowed into the soil before planting. Farmers who do not raise livestock or have no organic manure or who reside in large-scale intensive mechanized farming area, choose ammonium phosphate, nitrolime, urea and mixed fertilizers as base-fertilizer. Auxiliary-fertilizer is applied during crop growth, and urea and mixed fertilizer are mostly used as auxiliary-fertilizer. Fertilizer type, application time, method and amount largely depend on regional agronomic practices, and on farmers' experience and knowledge of farming. In addition, guides from the regional governments and advertisement agencies further influence fertilizer application. For example, farmers in Taihe prefer mixed fertilizers because local community agents tell them it is most balanced for healthy crop growth. On the other hand, farmers in Fukang believed that the urea is quick-acting as advertised by fertilizer companies.

In terms of application method, fertigation (i.e. drainage of channel irrigation water following fertilization) is the dominant method in irrigated agricultural systems of Yucheng. In other areas, whole-layer application (i.e. mixing soil with fertilizer during excavation) and spot application are the dominant application methods. Generally, spot application and whole-layer application is used for base-fertilizer. In intensive irrigated agricultural systems of Yucheng, fertigation is common, especially for auxiliary-fertilizer. In centralized paddy-field systems of Taoyuan, surface application is often used for auxiliary-fertilizer, saving farmers some labor. On the other hand, decentralized hilly paddy-field systems of Taihe mainly use whole-layer fertilization in order to minimize fertilizer loss.

Nitrogen content widely varies with fertilizer type—45–50% for urea, 15–17% for mixed fertilizers and 18% for ammonium phosphate. Fertilizer type also determines the rate of nitrogen discharge into river and ammonium vaporization. Nitrolime, for example, is a slow-acting fertilizer containing carbonic acid (with a mild acidity) that is highly absorptive to soil colloids. In addition, dicyandiamide (partially a secondary product of cyanamidic nitrogen in nitrolime) inhibits nitrification by delaying conversion of ammonia nitrogen to nitrate nitrogen, hence retaining ammonia nitrogen in the soil for a longer period of time. As a result of this, there is little nitrogen outflow from nitrolime. Urea, on the other hand, is water-soluble and readily nitrifies, and is therefore discharged into water bodies at a higher rate than nitrolime. Furthermore, fertilizer application methods impact nitrogen outflow. For example, large-scale whole-layer application of ammonium nitrogen (e.g., urea) is feasible in cultivated lands; hence nitrification is rapid, as is the rate of nitrate nitrogen discharge into water bodies. Spot application leads to less nitrogen outflow than whole-layer application.

Therefore environmental nitrogen loading originating from chemical fertilizers depends heavily on fertilizer type and application method. The discharge rate of chemical fertilizer-derived nitrogen into rivers is influenced by a number of ecosystem-specific factors including precipitation, irrigation frequency, temperature, topography and soil pH; which is yet to be adequately quantified. Our results, however, underscore the importance of including chemical fertilizer type and application method in regional nitrogen flow analysis.

Agricultural by-product recycling

Environmental nitrogen loading originating from agricultural by-products like straw depends heavily on how the by-products are utilized. Field data on agricultural by-product utilization are summarized in Fig. 7. In double cropping (which common in the paddy-field agricultural system of Taihe and Taoyuan), by-products from the first crop are usually burned because of the limited time between the first harvest and second seeding. After harvest, by-products from the second crop are usually left on the field and mixed with base-fertilizer and soil (the following year) during excavation. In Yucheng, over 70% of agricultural by-products like wheat straw are collected and recycled in livestock feed, barn bedding material and cooking fuel. Farmers sometimes sell surplus straw to neighborhood livestock breeders. Such practice ia mainly driven by the "effective waste reuse and zero emission" drive promulgated by Yucheng government. In the oasis agricultural

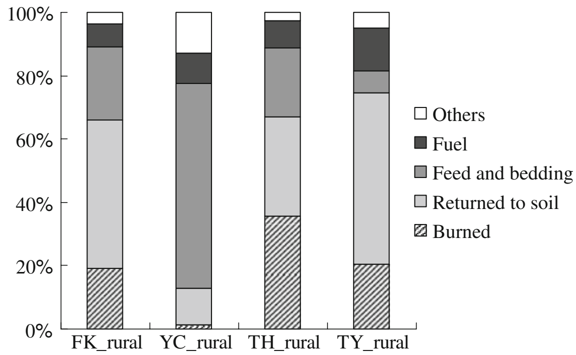

Fig. 7 Utilization of agricultural by-product

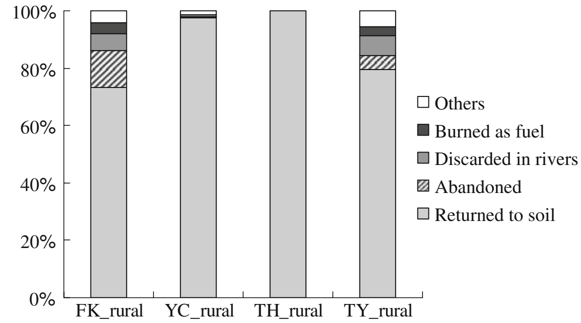

Fig. 8 Utilization of livestock excreta

systems, which primarily grow spring wheat via single cropping thereby offering an abundant livestock feed in the vast natural grasslands, most agricultural by-products are left on the fields and recycled as organic fertilizer.

Livestock excrement recycling

Environmental nitrogen loading originating from livestock excrement also heavily depends on how the waste is utilized. Field data on the utilization of livestock excrement is summarized in Fig. 8. Most livestock excrements are reused and naturally reduced in the fields and pasturelands. In Fukang and Taoyuan where large-scale livestock breeding is common, livestock excrement is sometimes abandoned or disposed into rivers. In our investigation, we noted some decline in traditional small-scale household livestock breeding, whereas intensive large-scale livestock breeding increased. This change is mainly due to (1) most of the youngsters leave for cities or towns as migrant workers leading to manpower shortage in rural areas; and (2) the cost of small-scale household livestock breeding is relatively high hence low economic benefit. Although excrement generated in small-scale household livestock breeding is largely reused in farmlands as manure (shown in the study, by increasing meat consumption and large-scale livestock breeding), nitrogen loading from livestock excrement is potential environmental problem. This should be adequately redressed for a healthy sustainable environment.

Change in consumption and future food preference

Result regarding food consumption change in the last 10 years is plotted in Fig. 9. Consumption of non-crop foods has increased over the last 10 years. This is especially remarkable for rich-protein foods like pork, chicken, egg, fish and milk, but also for vegetables and fruits. Moreover, there are remarkable changes in the characteristics of the respective regions. For instance, traditional foods like crops and pork decreased, while foods like beef, mutton, egg, fish and milk increased for Shijiazhuang. This is a clear indication of a diversified eating habit of the population. In the rural areas of Fukang (where socio-economic standard is relatively low), there is remarkable increase in grain consumption. In Taihe and especially in the rural areas of Taihe, there is a remarkably higher increase in the consumption of pork, chicken, egg, fish and fruits than in other regions. Meat and fruit consumption is increasing despite low overall food consumption in these regions. In Wuhan, consumption is increasing for all foods, mainly driven by high influx university students into the area.

Future food preferences are plotted in Fig. 10. In all the regions, there is an increasing consumption tendency for meat, vegetables and fruits, implying higher consumption of these food stuffs with time. In addition, a number of people now seek nourishment replenishment through nutrient supplement. This suggests that nutritional balance will be more aggressively pursued in the near future.

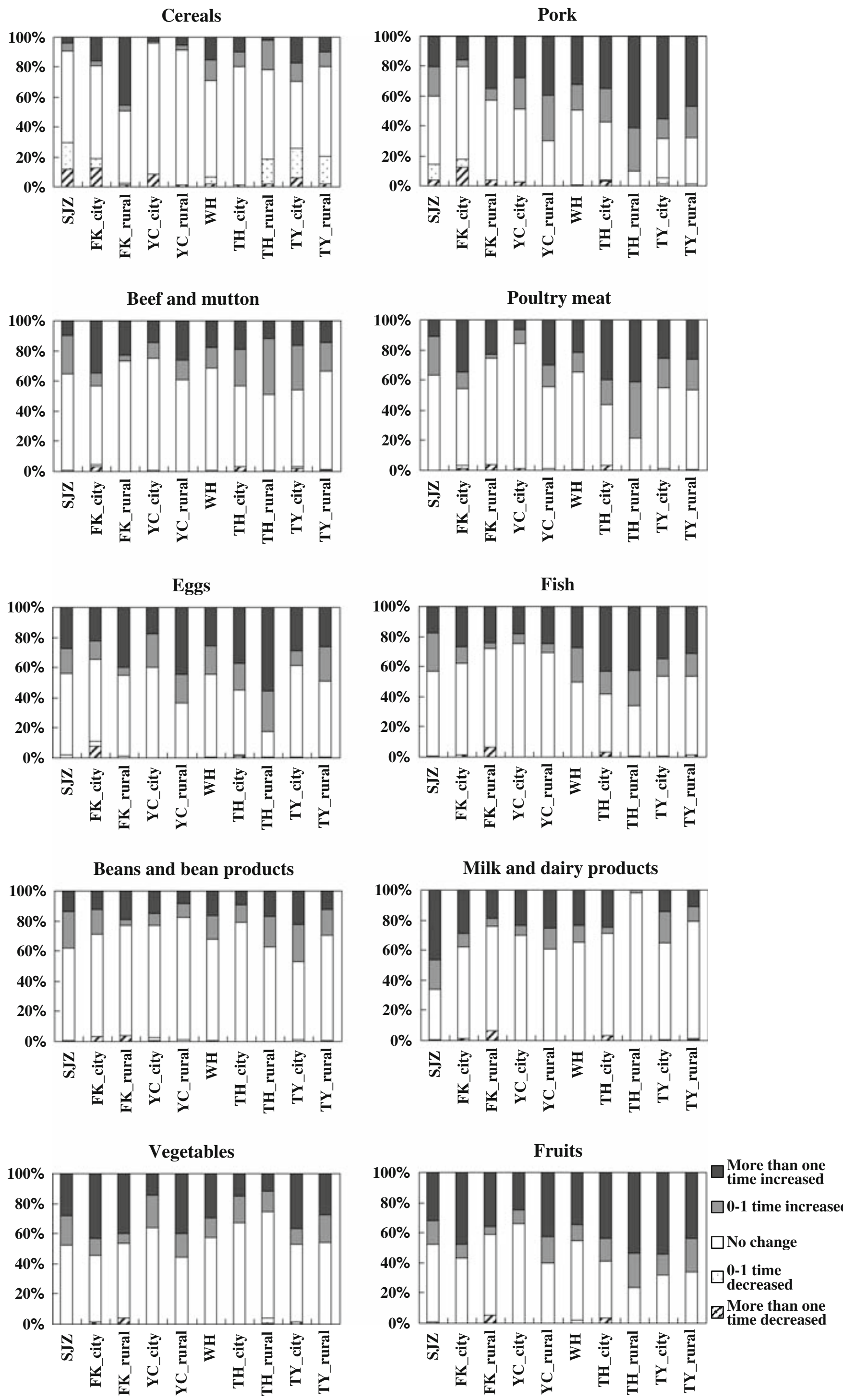

Fig. 9 Consumption change of each foods

Conclusions

The present study identifies, via field investigation of six typical ecosystems in China, parameters of regional nitrogen balance models. Such parameters include human dietary nitrogen intake, amount of nitrogen discharge into soils and rivers through waste, types and application rates of nitrogen

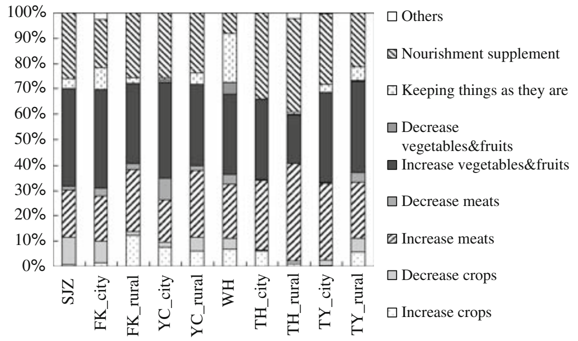

Fig. 10 Future preferences of each foods

chemical fertilizers used in farming, and discharge pathways of nitrogen in agricultural by-products and livestock excrement.

Based on field investigation data, grain consumption is higher in North China (a wheat-culture base) than in South China (a rice-culture base). Compared with food consumption structure in the last decade, the current population eats far more non-grain foods, especially non-grain foods like pork, chicken, egg, fish, dairy products, vegetables and fruits. In terms of future consumption preferences, the survey indicates an increasing demand potential for vegetables, fruits and animal-based food products like meat in the diet of the Chinese population. Some respondents seek nutritional supplements, suggesting that better nutritional balance is a growing concern among the people. Striking regional differences are also noted in the study. Shijiazhuang, for instance, is experiencing a remarkable diversification of dietary habit, in which people consume more beef, mutton, egg, fish and dairy products in place of conventional foods like grain and pork. In the economically disadvantaged rural areas of Fukang, rice and wheat consumption is on the rise, and is happening so at a rate not precedented in other regions. Yucheng and Taoyuan (where centralized agricultural system is common) are experiencing rapid farm modernization and urbanization, narrowing the gap between the urban rich and the rural poor. Differences between urban and rural areas are particularly remarkable in the oasis agricultural ecosystems of Fukang and also in the hilly decentralized agricultural ecosystems of Taihe. These areas experience rapid increase in dietary protein intake, with residents expressing intentions to add more protein-rich foods to their diet. These changes are likely to reflect local socio-economic levels and growth. Protein intake through meat-based diet is expected to increase not only in the urban rich areas, but also the rural poor settlements of China.

Due to well-developed sewage and flush toilet systems, the rate of human excrement return to the soil is low in urban areas, with most of the waste discharged into open water bodies. In rural areas, human excrement is often recycled as organic fertilizer and returned to the soil. In more urbanized rural areas (e.g., Taoyuan), however, we observe a proliferation of flush toilet, coupled with a lower rate of human excrement return to the soil. An arising concern regarding increasing urbanization and urban dweller population is the inability to process huge volumes of generated human excrement, which would result in excessive environmental nitrogen loading. In addition, hydrologic problems including limited aquatic resources, sufficient and quality drinking water and deterioration of water environment are very much linked to the issues of excrement and organic waste. Therefore, there is a dire need to construct treatment systems so as to enable waste circulation and recycling thereby accommodating the changing needs of the nation.

Currently, most livestock excrement is reduced in the fields and pasturelands. Before then, farmers would raise 3–5 pigs per household. Such practices have been largely abandoned over years due to high labor and time requirement, market instability, high costs for feed, and unprofitable and unreasonable meat pricing system. Also, as the number of large-scale livestock breeding centers introduced via external financing is on the rise, waste discharge pathways for these livestock breeding centers could not be identify. Most livestock breeding centers are, however, not equipped with wastewater processing systems, raising concerns about the possibility of pollution of the river systems from excessive livestock excrement.

In the light of the above, further research is recommended toward improvements in the investigated parameters for regional nitrogen balance models. For example, a long-term investigation with selected respondents will be necessary to investigate the changing patterns of life-style and farming method. Under an effort to build a "harmonious society", the government of the People's Republic of

China has proposed large-scale environmental technology and environmental conservation projects. We therefore intend to do further research on the current and future effectiveness and outcome of such technologies and conservation projects. This would bring an entirely new contribution to the literature, and the protection and management of the environment.

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Appendix

See Table 4.

Table 4 Characteristics of the respondents

		SJZ	FK_urban	FK_rural	YC_urban	YC_rural	WH	TH_urban	TH_rural	TY_urban	TY_rural
Sex	Male	79	25	42	83	147	49	66	124	133	127
	Female	75	36	14	43	19	52	34	29	68	57
	No answer		2	19		6	5				
Age (years)	16–20		8	11		1	4	5			1
	20–30	43	1	2	11	16	77	22	6	19	21
	30–40	53	43	38	65	39	11	29	42	51	43
	40–50	48	7	18	31	64	11	27	56	72	56
	50–60	10	3		10	37	2	13	36	44	43
	60–70			1	6	11		1	13	13	18
	≥70				1	4		3		2	2
	No answer		1	5	2		1				
	Average	37	35	35	41	46	26	40	46	45	46
Height (cm)	<140			1			1	1			
	140–150	2	3	1			2	10	1	3	4
	150–160	46	19	11	16	20	30	39	39	55	58
	160–170	49	25	32	44	91	40	41	90	105	97
	≥170	52	15	26	66	61	33	9	23	38	25
	No answer	5	1	4							
	Average	166	165	168	169	169	166	162	165	165	165
Weight (kg)	<40		5	3		1		4	2	4	1
	40–50	8	7	11	3	1	32	25	25	29	35
	50–60	49	20	19	41	24	31	40	84	72	73
	60–70	57	14	21	49	102	27	20	40	74	59
	70–80	25	11	15	28	38	8	11	2	17	15
	≥80	12	5	3	5	5	7			5	1
	No answer	3	1	3		1	1				
	Average	64	62	63	66	67	61	57	57	60	60
Household registration	Rural residents	26	6	14	33	148	18	19	146	70	123
	City (non-rural) residents	128	51	50	81	16	85	81	7	130	59
	No answer		6	11	12	8	3			1	2

Table 4 continued

		SJZ	FK_urban	FK_rural	YC_urban	YC_rural	WH	TH_urban	TH_rural	TY_urban	TY_rural
Occupation	Farmers	18		35	31	134	6	6	146	32	100
	Workers	17	4	13	26	9	2	16	3	17	12
	Company	33	3	2		1	1			9	8
	Officers	13	13	1	25		6	9		23	24
	Technicians	31	1	3	9	3	1	9	1	20	4
	Corporate managers	12	5	1	6		2	6		1	4
	Individual managers	16	13	4	12	7	8	17	1	29	15
	Students	14	7	7		3	64	13			2
	Doctors		1		4	1	1	15		6	3
	Teachers		7		10	5	8	9	1	5	1
	Researchers						1				
	Retirees		1	1						6	3
	Housewives		2	1			2			4	1
	The unemployed	5	1			1			2	1	
	Others		1	1			2			37	4
	No answer			5	3	9	1		1	10	2
Education level	Elementary school	6	7	4	16	19	1	12	41	35	41
	Middle school	23	6	46	24	106	3	27	90	50	58
	High school	54	14	15	41	24	16	28	21	59	39
	University and higher	71	31	4	24	9	77	31		46	38
	No answer		5	6	21	14	9	2	1	11	8
Intensity of daily activity *	Low	8	3	1	14	6		15		12	12
	Medium	110	40	35	63	52	89	52	49	122	77
	High	35	16	32	40	97	15	31	104	67	92
	No answer	1	4	7	9	17	2	2			3
Family number (persons)	1	4					5			35	2
	2	24	2	2	14	27	2	6	4	50	21
	3	97	43	21	84	42	61	50	24	59	85
	4	17	15	31	24	80	25	18	51	46	44
	5	11	2	15	1	17	11	14	40		21
	>5	1	1	6	3	5	6	3	34		9
	No answer						1	4		11	2
	Average	3.1	3.3	4.0	3.2	3.6	3.6	3.4	4.6	3.4	3.5
Family living floor space (m^2)	<100	80	47	65	71	72	49	49	78	61	37
	100–500	73	13	4	52	65	42	49	74	138	137
	500–1,000	1	1		1	17			1	1	3
	≥1,000					18					2
	No answer		2	6	2		15	2		1	5
	Average	109	94	60	98	211	115	107	119	133	150

Table 4 continued

		SJZ	FK_urban	FK_rural	YC_urban	YC_rural	WH	TH_urban	TH_rural	TY_urban	TY_rural
Family income per year (yuan)	<5,000		4	35	4	43	9	5	3	24	8
	5,000–10,000	11	8	21	13	23	9	13	25	48	33
	10,000–20,000	26	26	5	34	75	9	37	85	68	94
	20,000–50,000	96	18	2	70	29	28	36	38	55	38
	≥50,000	21	1		3	1	24	3	1	4	3
	No answer		6	12	2	1	27	6	1	2	8
	Average	36,746	20,216	6,814	27,653	13,693	55,401	27,184	17,156	18,997	19,701
Income per capita per year (yuan)	<2,000	1	5	48		43	13	7	14	40	10
	2,000–5,000	13	17	12	38	84	12	26	118	63	94
	5,000–10,000	64	32	2	48	42	13	49	20	71	54
	≥10,000	76	3	1	38	1	41	12		25	17
	No answer		6	12	2	2	27	6	1	2	9
	Average	12,490	6,288	1,908	8,816	3,842	17,676	8,379	3,728	5,995	6,022

* *Low:* A sedentary lifestyle, the majority of the time is spent seated

Medium: Though a large proportion of the time is spent seated, there is some movement in the office; work and service are performed while standing; also includes shopping, housework, and non-strenuous sports

High: Employment involving a considerable amount of movement or standing, or persons partaking in active leisure pursuits such as sports

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