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Predictive Analysis of Nitrogen Balances Resulting from the Production and Consumption of Livestock Products in the Huang-Huai-Hai Region, China

Zhihong SHEN*, Eiichi KUSANO, Hsiaoping CHIEN and Osamu KOYAMA

Research Strategy Office, Japan International Research Center for Agricultural Sciences (Tsukuba, Ibaraki 305-8686, Japan)

Abstract

The purpose of this study is to propose an integrated projection methodology to manage the livestock industry in China sustainably and generate useful data in this context. To achieve this, we constructed a comprehensive set of models, comprising food supply-demand-, nitrogen balance-, and environmental evaluation models respectively. This study focuses on analyzing medium- and long-term projections of the supply-demand balance of nitrogen nutrients in the Huang-Huai-Hai region as well as on the environmental impact due to the influence of livestock products.

Discipline: Agricultural environment & Agricultural economic
Additional key words: environmental impact, food supply-demand, partial equilibrium, recycling ratios

Introduction

Economic development, population growth, and rising personal incomes are not only the main catalysts for changes in food preferences and agriculture, but also exert negative impacts on the environment, including the air and water in China. While trends in per-capita grain consumption in China are showing gradual decline, the per-capita consumption of livestock products has tended to soar, in a manner similar to that observed in other countries (FAO:FAOSTAT 2011). However, nitrogen emissions from livestock production have not been seriously considered as industrial emissions; despite the fact livestock contributes more nitrogen than the industrial sector (Li et al. 2000). In addition, nitrogen emissions account for 63-83% of total livestock nitrogen output (Dong et al. 2011); significantly exacerbating the eutrophication of lakes and rivers (Li et al. 2000). The Huang-Huai-Hai plain, one of China's principal agricultural centers, is an alluvial plain developed by the intermittent flooding of the Huanghe, Huaihe, and Haihe rivers. The target area of this study is defined as the Huang-Huai-Hai (3H) region, which comprises two municipalities and three provinces (Beijing, Tianjin, Hebei, Shandong, and Henan), based on administrative divisions and research feasibility. 2010 statistics show that the 3H region covers a total area of about 539,420 km^2, 224,318 km^2 of which is cultivated and accounting for 18% of China (NBSC 1991 - 2011). Although the land area in the 3H region is only 4% of China, its grain and livestock production account for 18 and 29%, respectively, of China's totals. The population in the 3H region accounts for 21.5% of China's people, and it has a high population density (5.3 times greater than the national average). In most of the 3H region, nitrogen emissions per unit area exceed 150 kg/ha·y (Wei et al. 2008). In Beijing meanwhile, the Nitrogen Emission Intensity [230 kg/ha·y] (Wei et al. 2008) far exceeds the level stipulated by European regulations [170 kg/ha·y] (DEFRA 2009, Fraters et al 2008), which significantly threatens the aquatic environment. Accordingly, there is a need to identify the structure of nitrogen emissions and project their future evolution, to ease the environmental burden in the region.

Based on Material Flow Analysis (Fischer Kowalski 1998), many methods have been created to research the nitrogen cycle. Isermann and Isermann (Isermann & Isermann 1998) developed a nitrogen balance model using statistical data for Germany for the 1995-1998 period, which considers grain, livestock, and waste to analyze the national nitrogen balance. The INITIATOR (De Vries et al. 2003) and STONE models (Wolf et al. 2003, Wolf et al. 2005) focus on regional environmental evaluation, by calculating nitrogen input-output and nitrogen loss, using the proportional distribution principle. The MITERRA-EUROPE model (Oenema et al. 2009, Velthof et al. 2009), which has

*Corresponding author: e-mail hirosi98@affrc.go.jp
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been widely used as a tool to manage nutrients in Europe, was developed based on the STONE model in 2007. Most studies concerning the nitrogen cycle in China have been limited to national-scale research. Liu (Liu 2005) built a national nitrogen model which considers three aspects - agriculture, livestock, and environment - and analyzed the nitrogen input-output during 2001. Ma (Ma 2005) created a Nutrient Flow Cycle model based on the models developed by Isermann and Isermann (Isermann & Isermann 1998) and Liu (Liu 2005). However, it only calculates runoff losses caused by feces from livestock. The model was applied using national data for the period 1998 - 2004, as well as regional data for the period 2002 - 2004 from the Northeast and Hebei provinces. However, all these studies in China only analyzed the nitrogen balance and its environmental impact during the study period. Because these previous studies focused on a national scale at the time, they lacked regional perspectives, as well as analyses of medium- and long-term trends.

To better understand trends related to the regional nitrogen cycle associated with the production and consumption of livestock products, which is the major and increasing source of nitrogen emissions in the region, we refined a projective methodology for livestock products, selecting an optimal range for parameter estimates, and inputting relevant livestock statistics. To simplify the calculations, and estimate the nitrogen cycle more accurately, we improved the structural elements of previous models for nitrogen livestock production and household consumption, and created an integrated projective model that encompassed the nitrogen cycle. The models use the latest available data from major provinces in China. Using a case study of the 3H region, we developed medium- and long-term projections of the environmental impact of economic activity. Furthermore, we also developed projections of the demand for and supply of nitrogen nutrients by livestock product items in each province for the period 2011 - 2020. The purpose of this study is to better understand trends in the nitrogen nutrient balance and related risk factors, and provide a meaningful scientific basis for livestock management strategies.

Methods

The research approach utilized in this study involved four steps. The first was to build a partial equilibrium model of livestock products, estimating the parameters for the food supply-demand model, and thus enabling the food supply-demand for each province to be predicted. During the second stage, variables for the nitrogen balance model were identified based on parameters from the investigative data and research literature. Subsequently, a nitrogen balance model for the 3H region was created using material flow analysis linked to the partial equilibrium model developed during the first step. In the final step, we analyzed the nitrogen supply-demand, environmental impact, production efficiency, and recycling ratio in each area through projections, thereby exploring options for more sustainable production and consumption of livestock products in the 3H region.

1. Model structure

For this study, we constructed an integrated projective model comprising a partial equilibrium model for food supply-demand, a nitrogen balance model, and an environmental evaluation model, as shown in Figure 1. This model is a research roadmap which includes an integrated approach

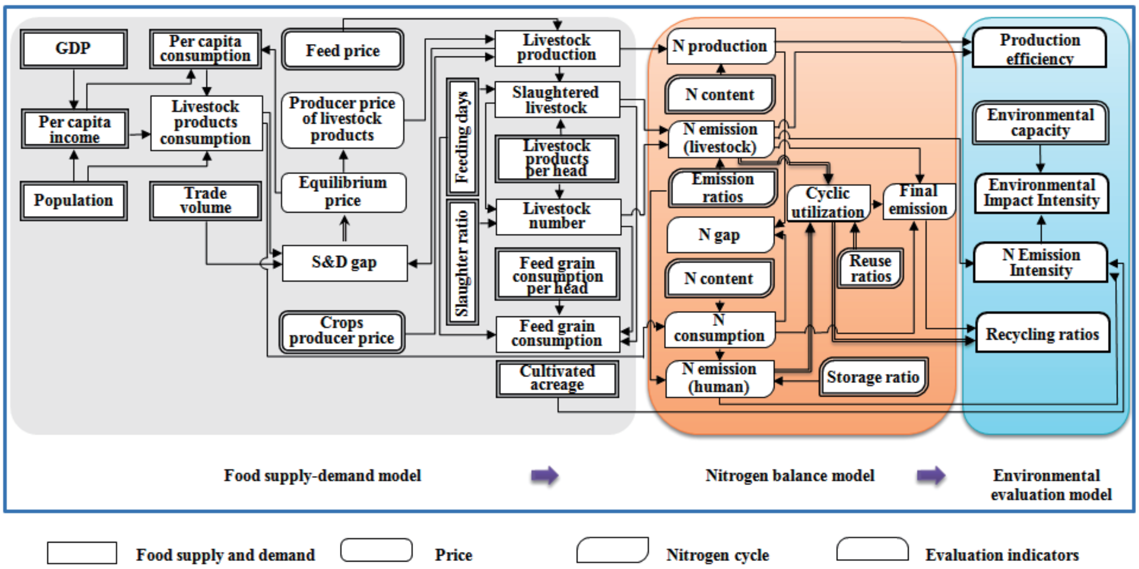

Fig. 1. Projection model structure
Note: Double- and single-border boxes refer to exogenous and endogenous variables, respectively.

towards the projective analysis of nitrogen emissions derived from livestock. Such an approach prioritizes the interlinked and interactive relationships between socioeconomic growth, production-consumption, and the global market. These are important considerations when projecting the supply-demand of nitrogen nutrition and analyzing the degree of environmental pollution likely to occur in future, particularly in an increasingly complex and ever-changing market environment. The relevant formula definitions are described in Tables 1, 2, and 3. In the food supply-demand model, livestock was assumed to be produced in 31 areas to meet national demand. Six kinds of livestock (namely pigs, beef cattle, dairy cattle, sheep, broiler, and hens) were selected as items for analysis. The starting year was determined by obtaining an optimal parameter for each area between 1996 and 2010. The respective initial values for per-capita consumption, production volume, producer prices of major food items, and grain acreage were decided by repeatedly minimizing the difference between the estimated and actual values of each item in the different areas. The end year was set to 2020.

The annual values were estimated as follows. Population and GDP were assumed to be exogenous variables. Market prices were determined when the gap between supply and demand was zero; the gaps were estimated based on national food consumption, regional food production, and trade volume. To estimate the nitrogen balance, it is important to analyze the material flows of the livestock production sector and those of the domestic consumption sector. This approach has two major structural differences compared to previous research models. First, the parameters were estimated based on provincial data, instead of sharing the same parameters across regions with similar properties, as was done in previous research (Chen 2004). Second, this model combined food supply-demand, nitrogen balance, and environmental evaluation. The projection analysis considered the dynamic impacts of market price changes on production-consumption and indirectly on the nitrogen cycle.

2. Parameters and validation

The parameters for the supply-demand model were selected by applying the double logarithmic type, and chosen based on absolute value, sign condition, t value, determination coefficient, and the stability of the model in the final test. From Table 4, the key estimated parameters were consistent with Kusano et al. (Kusano et al. 2014) due to only one year of difference in the observed data. The values for the main exogenous variables were obtained by extrapolating trend values using a linear function. For such extrapolation, clearly different outliers and slopes for each item were avoided, which meant estimation was conducted selecting stable periods, and the most recent values were used. Net exports (national total) do not exhibit clear trends. Accordingly, their value was set as the average of the previous three-year period. Baseline estimates for 2011 - 2020 are based on the annual rate of change, which was determined based on the mean rate of change over the period 2000 - 2010. Since no extreme divergence was observed, the results of the baseline estimate are considered realistic.

Models and parameters derived from literature and statistical data were used to estimate the nitrogen balance, as well as for environmental evaluation (Tables 2 and 3). To facilitate the calculation of the nitrogen balance, we selected 28 parameters (Tables 2, 3, and 5), which are closely related to the production and consumption of livestock products. We integrated the emission factors of animals with the sum of the products of unit emissions of different excreta and their nitrogen contents. Similarly, the nitrogen content of the inedible portions was calculated through the sum of the products between their weights and nitrogen contents, whereupon we calculated the coefficient of relative nitrogen content as the ratio of the inedible portion to the edible portion. The main parameters are shown in Table 5.

Results and discussion

1. Trends of regional gaps in nitrogen derived from livestock products

Nitrogen in livestock products as a food nutrient can be consumed interchangeably. From this perspective, we integrated the nitrogen in major livestock products in each area. Figure 2 shows that areas with large surpluses in descending order are Shandong (94 kiloton N), Hebei (49 kiloton N), and Henan (40 kiloton N), accounting for 2.6, 6.5, and 5.3% of total consumption, respectively. However, the areas with large deficits are Beijing (42 kiloton N) and Tianjin (13 kiloton N), with deficits of 3.2 and 2.4 times larger than their 2010 values, accounting for 79.5 and 35.1% of local consumption, respectively. The surplus of nitrogen in the 3H region still remains at 17% of consumption, which signifies that despite significant deficits in some areas, allocating livestock products effectively can still ensure a secure supply of nitrogen nutrition in the 3H region.

Figure 3 shows that the livestock products with large surpluses are eggs and chickens, about 119 kiloton N (40% increase) and 25 kiloton N (4% increase), accounting for 60.9 and 15.9% of total consumption in 2020, respectively. Both milk and beef maintain low surpluses of about 10 kiloton N (40% decrease) and 3 kiloton N (90% decrease), accounting for 8.3 and 4.4% of total consumption in 2020, respectively. However, the deficit for pork is the largest, at about 27 kiloton N and accounting for 15.3% of total consumption, followed by the deficit is for mutton, about 2 kiloton N (2.8 times that of 2010), accounting for 5.1% of consumption. This is a result of changes in dietary habits, as well as the distribution of resources for production.

Table 1. Definitions of formulae and structural equations for the integrated mode

	Items	Unit	Definition formula · Structural equation			Sources
Food supply-demand model						
(1)	National population	persons	POP_t	:	Exogenous variable	UN 2010
(2)	Provincial population	persons	$\hat{POP}_{m,t}$	=	$\hat{POP}_{m,t-1} \cdot (\hat{POP}_t / \hat{POP}_{t-1})^{\beta}$	NBSC 1991-2011, UN 2010
(3)	GDP	Yuan	GDP_t	:	Exogenous variable	IMF 2011
(4)	Per capita income	Yuan/person	GPP_t	=	GDP_t / POP_t	---
(5)	Market price [*1] (Equilibrium price)	Yuan/kg	$PMK_{i,t}$	←	$\lvert GAP_{i,t} \rvert \approx 0$	---
(6)	Demand-Supply Gap	ton	$GAP_{i,t}$	=	$\Sigma_k QSS_{i,m,t} - QDD_{i,t} - TRD_{i,t}$	---
(7)	Livestock product consumption	ton	$QDD_{i,t}$	=	$QDP_{i,t} \cdot POP_t$	---
(8)	Per capita consumption	ton/person	$QDP_{i,t}$	=	$QDP_{i,t-1} \cdot (PMK_{i,t} / PMK_{i,t-1})^{\alpha} \cdot (GPP_t / GPP_{t-1})^{\beta}$	---
(9)	Livestock products [*2]	ton	$QSS_{i,m,t}$	=	$QSS_{i,m,t-1} \cdot \Pi_i (PPR_{i,t} / PPR_{i,t-1})^{\alpha} \cdot (PPC_{k,t} / PPC_{k,t-1})^{\beta} \cdot (PPF_t / PPF_{t-1})^{\gamma}$	CAYEC 2009, CAYEC 2010-2011
(10)	Cultivated area	ha	$CA_{m,t}$	:	Exogenous variable	NBSC 1991-2011
(11)	Crop producer price	Yuan/kg	$PPC_{k,t}$	:	Exogenous variable	FAO 2011
(12)	Producer price of livestock products	Yuan/kg	$PPR_{i,t}$	=	$PPR_{i,t-1} \cdot (PMK_{i,t} / PMK_{i,t-1})$	FAO 2011
(13)	Feed price	index	PPF_t	:	Exogenous variable	NBSC-DRSNBS 2004-2011
(14)	Trade volume (net export)	ton	$TRD_{i,t}$	:	Exogenous variable	FAO 2011
(15)	Stock of pig, cattle, mutton, and poultry	head	$INV_{i,m,t}$	=	$SLT_{i,m,t} / TOV_{i,m,t} - SLT_{i,m,t}$	CAYEC 2009, CAYEC 2010-2011
(16)	Stock of dairy cattle and hens	head	$INV_{i,m,t}$	=	$QSS_{i,m,t} / YLD_{i,m,t}$	---
(17)	Stock of beef cattle and broiler [*3]	head	$INV_{i,m,t}$	=	$INV_{k,m,t} - INV_{j,m,t}$	---
(18)	Slaughtered pig, cattle, mutton, and poultry	head	$SLT_{i,m,t}$	=	$QSS_{i,m,t} / YLD_{i,m,t}$	CAYEC 2009, CAYEC 2010-2011
(19)	Slaughtered dairy cattle and hens [*4]	head	$SLT_{i,m,t}$	=	$1/DAY_{i,t} \cdot INV_{i,m,t} / (1/DAY_{i,t} \cdot INV_{i,m,t} + 1/DAY_{j,t} \cdot INV_{j,m,t}) \cdot SLT_{k,m,t}$	---
(20)	Slaughtered beef cattle and broiler [*3]	head	$SLT_{i,m,t}$	=	$SLT_{k,m,t} - SLT_{j,m,t}$	---
(21)	Slaughter ratio	%	$TOV_{i,m,t}$	:	Exogenous variable ($= SLT_{i,m,t} / (SLT_{i,m,t} + INV_{i,m,t})$)	---
(22)	Products per head	kg/head	$YLD_{i,m,t}$	:	Exogenous variable ($= QSS_{i,m,t} / SLT_{i,m,t}$)	FAO 2011
(23)	Feeding days	day	$DAY_{i,t}$	:	Exogenous variable	NDRC 1998-2010
(24)	Feed grain consumption	ton	QDF_t	=	$\Sigma_m QDF_{m,t}$	---
(25)	Feed grain consumption per head	kg/head	$RCN_{i,t}$	:	Exogenous variable	NDRC 1998-2010

Notes: Subscripts refer to the following: *i, j, k*: item of animal or livestock products; *m*: region; *t*: year. Item-related livestock products are pork, beef, mutton, chicken, milk, and eggs. Item-related livestock are pigs, cattle, sheep, poultry, dairy cattle, hens, beef cattle, and broiler. *1: Only used to calculate the milk retail price index; others use the peddlers' (rural) market price. *2: A period of adjustment is required for the price change, so the amount of milk production is shifted to the *t*-1 price. *3: When *i* represents beef cattle, *j* represents dairy cattle, and *k* represents cattle. When *i* represents hens, *j* represents broiler, and *k* represents poultry. *4: When *i* represents dairy cattle, *j* represents beef cattle, and *k* represents cattle.

Table 2. Definitions of formulae and structural equations for the integrated model (Continued 1)

Items	Unit		Definition formula · Structural equation	Sources
Nitrogen balance model				
(26) Nitrogen Gap	ton	$GAP_{m,t}$	$= \Sigma_i (OA^{products}_{i,m,t} - HC^{products}_{i,m,t})$	---
Livestock production in terms of nitrogen content				---
(27) Nitrogen input	ton	$IA_{i,m,t}$	$= OA_{i,m,t}$	---
(28) Nitrogen output	ton	$OA_{i,m,t}$	$= OA^{products}_{i,m,t} + OA^{by-product}_{i,m,t} + OA^{manure}_{i,m,t}$	---
(29) Nitrogen production *5	ton	$OA^{products}_{i,m,t}$	$= QSS_{i,m,t} * NC^{products}_{i}$	---
(30) Edible parts of mean nitrogen content	kg N/head·y	$NC^{products}_{i}$	: Exogenous variable	Wang 2006, Xu 2005 Yang 1999, Zhou 1999
(31) Nitrogen emissions (livestock excreta) *5	ton	$OA^{manure}_{i,m,t}$	$= \{(INV_{i,m,t} + INV_{i,m,t-1})/2 + SLT_{i,m,t} \cdot DAY_{i,t}/365\} \cdot NER^{livestock\ excreta}_{i}$	---
(32) Nitrogen emissions ratio of livestock excreta	index	$NER^{livestock\ excreta}_{i}$	: Exogenous variable	Liu 2007, Wang 2006 Xu 2005, Yang 2008
(33) Nitrogen emissions (by-product) *5	ton	$OA^{by-product}_{i,m,t}$	$= OA^{products}_{i,m,t} * PNC^{by-product}_{i}$	---
(34) Non-edible parts of relative nitrogen content	index	$PNC^{by-product}_{i}$	: Exogenous variable	Yang 1999, Zhou 1999 Xu 2005, Wang 2006
(35) Reused as compost (livestock manure) *5	ton	$OA^{compost}_{i,m,t}$	$= OA^{manure}_{i,m,t} \cdot NRR^{manure}_{i}$	---
(36) Mean percentage of livestock manure compost	%	NRR^{manure}_{i}	: Exogenous variable	Wang 2006
(37) Final emission of production	ton	$OA^{final}_{m,t}$	$= \Sigma_i (OA_{i,m,t} - OA^{products}_{i,m,t} - OA^{compost}_{i,m,t})$	---
Livestock product consumption in terms of nitrogen content				
(38) Nitrogen consumption	ton	$HC^{products}_{m,t}$	$= \Sigma_i (\hat{POP}_{m,t} \cdot QDP_{i,t} \cdot NC^{products}_{i})$	---
(39) Nitrogen emission of consumption	ton	$OH^{emission}_{m,t}$	$= HC^{products}_{m,t} - NS^{houman}_{m,t}$	---
(40) Storage in body	ton	$NS^{houman}_{m,t}$	$= HC^{products}_{m,t} \cdot NSR^{human}$	---
(41) Nitrogen emission (human excreta)	ton	$OH^{excreta}_{m,t}$	$= HC^{products}_{m,t} \cdot NER^{human\ excreta}$	---
(42) Reused as compost (human manure)	ton	$HMC^{compost}_{m,t}$	$= H^{excreta}_{m,t} \cdot NRR^{human\ excreta}$	---
(43) Reused as feed	ton	$HWU^{feed}_{m,t}$	$= HC^{products}_{m,t} \cdot NRR^{human\ waste}$	---
(44) Storage ratio for the human body *6	index	NSR^{hunman}	: Exogenous variable	Wei 2008
(45) Emission ratio for human excreta *6	index	$NER^{human\ excreta}$	: Exogenous variable	Wei 2008
(46) Reuse ratio for human manure compost *6	index	$NRR^{human\ excreta}$	: Exogenous variable	Wei 2008
(47) Reuse ratio for household waste utilization *6	index	$NRR^{human\ waste}$	: Exogenous variable	Wei 2008
(48) Final emission of consumption	ton	$OH^{final}_{m,t}$	$= OH^{emission}_{m,t} - HMC^{compost}_{m,t} - HWU^{feed}_{m,t}$	---
(49) Final emissions	ton	$OHA^{final}_{m,t}$	$= OA^{final}_{m,t} + OH^{final}_{m,t}$	---
(50) Cyclic utilization	ton	$NCU_{i,m,t}$	$= OA^{compost}_{i,m,t} + HMC^{compost}_{m,t} + HWU^{feed}_{m,t}$	---

Notes: *5: The parameters $NC^{products}_{i}$, $NER^{animal\ excreta}_{i}$, $PNC^{by-product}_{i}$, and NRR^{manure}_{i} are used to calculate the nitrogen balance of livestock production, as shown in Table 4. *6: The parameters NSR^{human}, $NER^{human\ excreta}$, $NRR^{human\ excreta}$, and $NRR^{human\ waste}$ are used to calculate the nitrogen balance of consumption of livestock products, and are 0.019, 0.836, 0.255, and 0.003, respectively.

Table 3. Definitions of formulae and structural equations for the integrated model (Continued 2)

Items	Unit		Definition formula · Structural equation	Sources
Environmental evaluation model				
(51) Nitrogen Emission Intensity (NEI) caused by livestock production *7	kg/ha·y	$NEI^{p}_{m,t}$	$= \Sigma_i OA^{manure}_{i,m,t} / CA_{m,t}$	---
(52) Nitrogen Emission Intensity caused by consumption of livestock products *7	kg/ha·y	$NEI^{c}_{m,t}$	$= (OH^{emission}_{m,t} - HWU^{feed}_{m,t}) / CA_{m,t}$	---
(53) Environmental Impact Intensity (EII) caused by livestock production *7	index	$EII^{p}_{m,t}$	$= NEI^{p}_{m,t} / EC_m$	---
(54) Environmental Impact Intensity caused by production and consumption of livestock products *7	index	$EII^{pc}_{m,t}$	$= (NEI^{p}_{m,t} + NEI^{c}_{m,t}) / EC_m$	---
(55) Environmental capacity *8	kg/ha·y	EC_m	: Exogenous variable	DEFRA 2009, DNEC 2002 Fraters 2008, Wei 2008
(56) Production efficiency	kg N/kg N	$PE_{i,m,t}$	$= OA^{products}_{i,m,t} / IA_{i,m,t}$	---
(57) Recycling ratio	index	$NCRA_{m,t}$	$= \Sigma_i NCU_{i,m,t} / (\Sigma_i NCU_{i,m,t} + OHA^{final}_{m,t})$	---

Notes: *7: NEI is an indicator used to evaluate the nitrogen emissions of production and consumption of livestock products. *8: EII is a "warning" variable used to define the pollution level resulting from livestock production and consumption. EII is divided into six classes (Shen et al. 1994). I: EII ≤ 0.4 (pollution-free), II: 0.4<EII ≤ 0.7 (minimal levels of pollution), III: 0.7<EII ≤ 1 (minor levels of pollution), IV: 1<EII ≤ 1.5 (pollution levels of slight concern), V: 1.5<EII ≤ 2.5 (pollution levels of serious concern), VI: EII > 2.5 (pollution levels of very serious concern). *8: Environmental capacity is set as 170 kg N/ha·y according to research results in China (DNEC 2002, Wolf et al. 2003) and Europe (DEFRA 2009, Fraters et al. 2008).

Table 4. Estimated parameters and relative error

Per capita consumption

	Constant term		Market price		Per capita GDP		Dummy		adj.R^2	Data period	Relative error
Pork	2.79	***	-0.05		0.42	***	-0.05	**	0.96	2002-2009	0.01
Beef	0.80	***	-0.14	**	0.55	***	0.06	**	0.99	2001-2009	0.01
Mutton	0.76	**	-0.53	***	0.95	***			0.96	2000-2009	0.03
Chicken	2.56	***	-0.92	**	1.02	***	-0.12	**	0.99	2002-2008	0.02
Milk	0.43		-1.03	**	1.38	***			0.90	2001-2010	0.14
Eggs	2.56	***	-0.26	*	0.44	***	-0.03	*	0.99	2000-2008	0.01

Production (median each province)

	Constant term	Producer price						Market price				
		Pork	Beef	Mutton	Chicken	Milk	Egg	Corn	Feed	adj.R^2	Data period	Relative error (province average)
Pork	-0.26	0.53			-0.17			0.39	1.19	0.70	1999-2009	0.06
Beef	-6.94	-0.68	0.74			0.23		0.35	-0.95	0.91	1998-2009	0.07
Mutton	-5.02			0.67		0.63		0.34	0.32	0.65	2000-2009	0.10
Chicken	-1.86	-1.02			0.77		-1.04	0.44	1.20	0.72	1998-2009	0.10
Milk	-13.01		1.55					-0.44	-1.05	0.90	1998-2009	0.17
Eggs	-3.48				-0.40		0.96		1.08	0.62	1999-2009	0.09

Notes: ***<.01, **<.05, *<.1. Adjusted R^2 obtained by OLS is reported for reference purposes. The results of regional dummies are abbreviated.

Table 5. Main parameters for the correlation between the input and output of nitrogen in livestock production

Items	Edible parts of mean nitrogen content $NC_i^{products}$	Non-edible parts of relative nitrogen content $PNC_i^{by\text{-}product}$	Items	Nitrogen emissions ratio of livestock excreta $NER_i^{animal\ excreta}$	Mean percentage of livestock manure compost NRR_i^{manure}
Pork	0.015	0.021	Pig	14.0	0.63
Mutton	0.021	0.017	Sheep	9.0	0.23
Milk	0.005	0.005	Dairy cattle	70.0	0.54
Eggs	0.022	0.000	Hens	0.6	0.22
Beef	0.028	0.025	Beef cattle	30.0	0.75
Chicken	0.027	0.012	Broiler	0.1	0.22

Notes: The unit for nitrogen emissions from animal manure is kg N/head·y. The other is an index (1=100%).

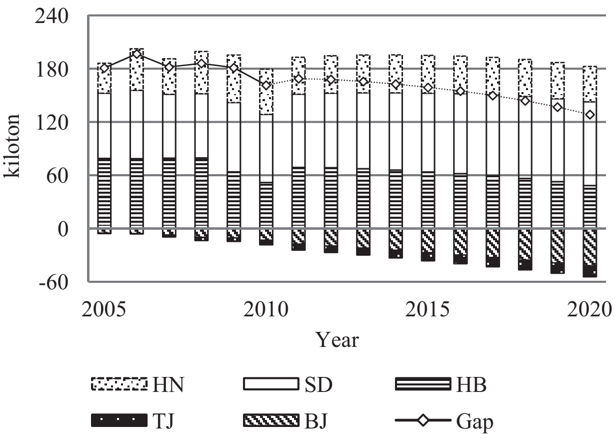

Fig. 2. Nitrogen gaps of livestock products

Notes: Bars indicate the nitrogen gaps of livestock products between production and consumption in each area. The line indicates the nitrogen gap of livestock products between production and consumption in the Huang-Huai-Hai region. Positive and negative indicate surpluses and deficits, respectively. Observed values are shown by a solid line, while estimated values are shown by a dotted line in the figures excepting Figures 1 and 6. Beijing, Tianjin, Hebei, Shandong, and Henan are abbreviated to BJ, TJ, HB, SD, and HN, respectively in Figures 2, 7, 8, and 9.

Environmental regulations related to livestock production also have a certain influence on future development trends. It is envisaged that in metropolitan cities, net income from livestock production will decrease due to strict nitrogen emission standards (MEP-PRC 2003), costlier production materials (NDRC 1998 - 2010), and imbalances in the distribution of profits (Hou et al. 2008, DAC 2011, Zhang & Chang 2009). As described above, the production of beef and pork will continue to decline in Beijing. The production of pork, beef, and mutton is thus likely to shift to high-efficiency agricultural areas where feed grain is produced, or low-cost pastoral areas, such as Henan, Hebei, Shandong, Inner Mongolia, Xinjiang, and Gansu (CAYEC 2009, CAYEC 2010 - 2011, NDRC 1998 - 2010, Zhang 2005). In Henan province, which is presently a pork production base accounting for 8.1% of national production in 2010, the first deficit (0.7 kiloton N) is expected to appear in 2020. The deficit for pork in the 3H region will thus be 5.4 times that of 2010. Mutton production relies on a traditional low input and low output system and projected results show that it will migrate to three specific areas. The first comprises the high technology areas in Hebei (increase of 0.20 kg/day), Shandong (increase of 0.14 kg/day), and Henan (increase of 0.11 kg/day). The second destination includes low maintenance cost areas in Shandong (31.65 Yuan/head) and Henan (35.87 Yuan/head). The third destination includes areas with abundant grassland resources according to the NAPCSC (NDRC 1998 - 2010). With the expansion in milk production, the roughage consumption ratio between sheep and dairy cattle will change from 1.31:1 in 2010 to 0.47:1 in 2020, which indicates that the shift in roughage is expected to increase constantly.

As shown above, the 3H region will face a serious shortage of pork and mutton. A common solution to this problem involves purchasing items elsewhere or expanding production. However, such economic activity will undoubtedly exert greater pressures on other areas and the environment. From environmental protection and resource management perspectives, we suggest that (1) the consumption of surplus livestock products should be stimulated by developing food-processing technology and innovative cooking techniques, and (2) pork production should be increased by improving production efficiency in the 3H region.

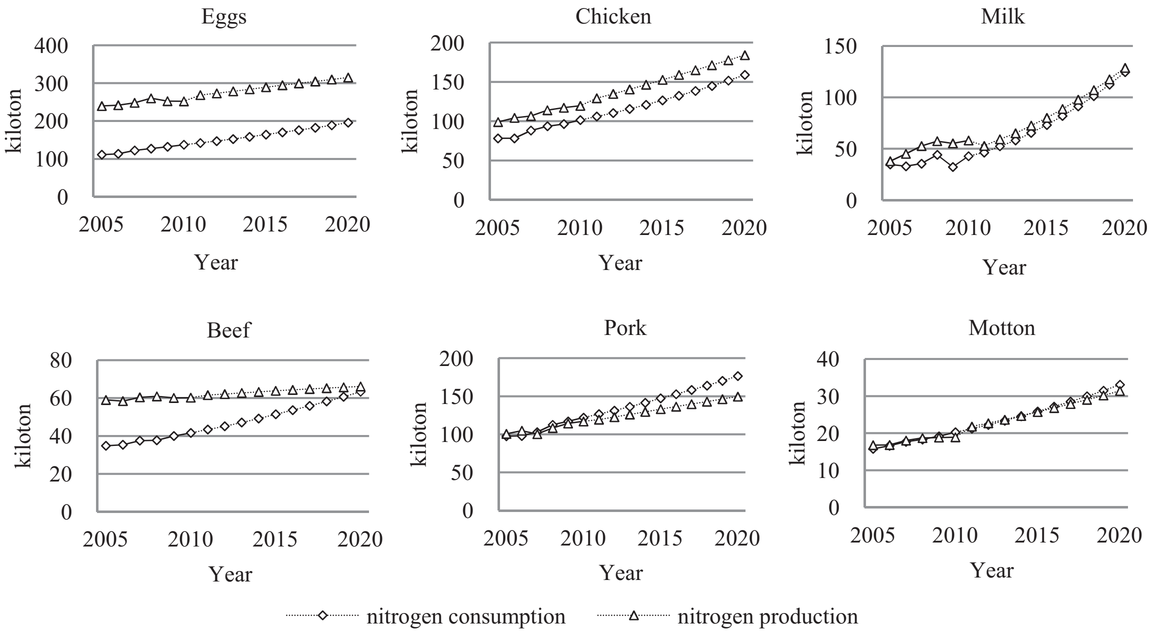

Fig. 3. Changes in production and consumption in terms of nitrogen content

2. Structural changes in livestock production and consumption in terms of nitrogen content

We can note the changes in the proportion of livestock products in terms of total nitrogen consumption (Fig. 4). By 2020, eggs and pork will be 26.2% (decrease of 3.4 points) and 23.6% (decrease of 2.7 points), as compared to 2010 values. Chicken and beef will decline slightly, remaining at about the 2010 level. However, mutton, with a slight growth trend, will be 4.4% (increase of 0.1 point). Milk, with a strong growth trend, will peak at 16.1% (increase of 7.1 points). These results indicate that consumer attitudes are changing from pork, chicken, and egg-based traditional consumption concepts to high-value and low-fat food-based modern consumption concepts. With soaring per-capita GDP, the new consumption concepts will trigger greater consumption of milk, beef, and mutton, and accelerate the proportional decline in pork consumption in the 3H region.

With the changes in consumption concepts, the changes in the contribution rates of livestock products to nitrogen nutrient production are substantial in the 3H region (Fig. 5). Eggs, pork, and beef drop to 35.9% (decrease of 4.3 points), 17.1 (decrease of 1.6 points), and 7.5% (decrease of 2.1 points), respectively. However, milk and mutton increase to 14.9% (increase of 5.6 points) and 3.6% (increase of 0.6 point) respectively. We examined the contributions of the livestock sector based on nationwide projection results (OECD - FAO 2013). Since both sets of results show a decreasing tendency in pork and beef and an increasing tendency in milk, it is thought that the livestock sector in the 3H region could represent the national trend.

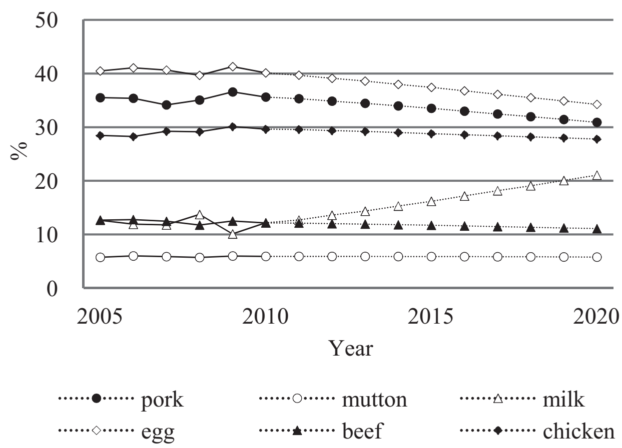

Fig. 4. Consumption structure of livestock products in terms of nitrogen content

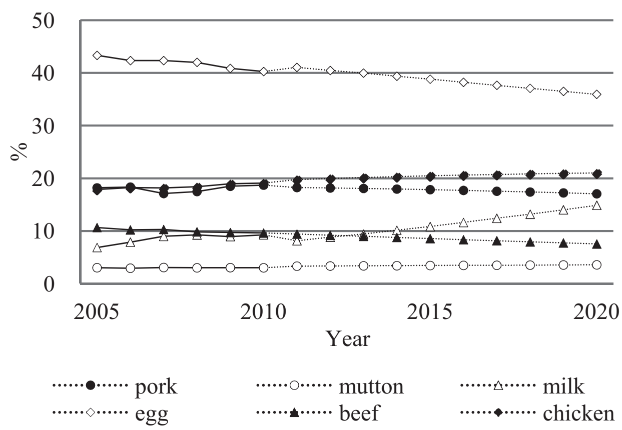

Fig. 5. Production structure of livestock products in terms of nitrogen content

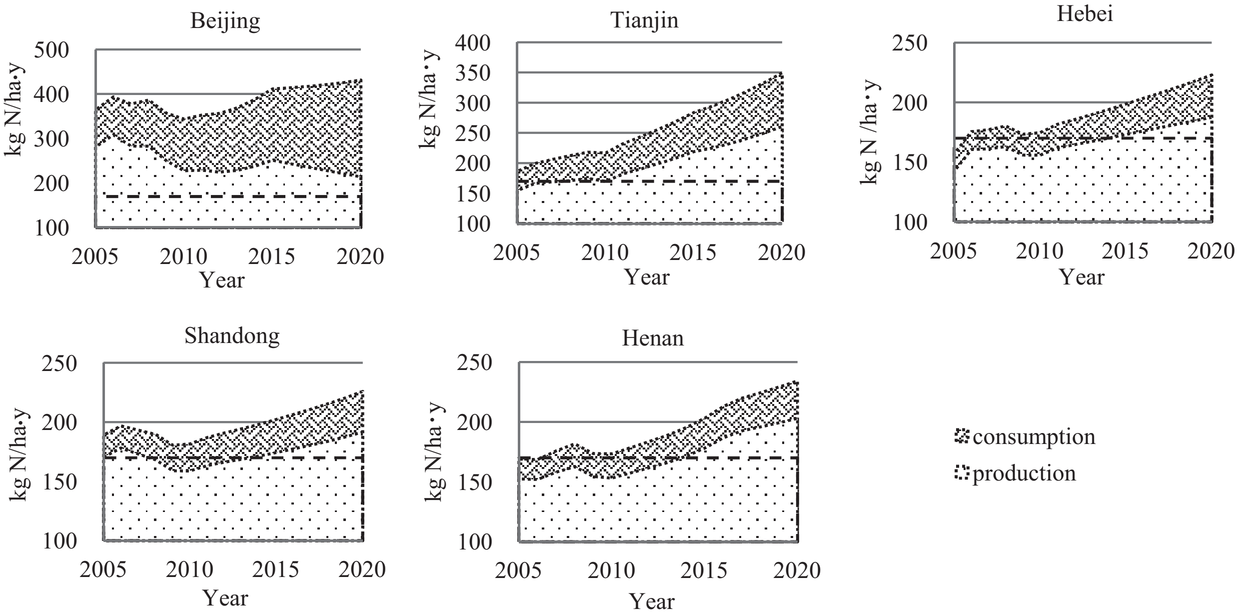

Fig. 6. Nitrogen Emission Intensity caused by livestock production and consumption

Notes: The marks of "production" and "consumption" mean the Nitrogen Emission Intensity caused by production (Table 3, 51st) and consumption of livestock products (Table 3, 52nd). The horizontal dashed line indicates the environmental capacity (Table 3, 55th, 170 kg N/ha·y).

3. Environmental impacts (NEI and EII)

With increasing incomes and population growth, nitrogen emissions (Table 3, 31st, 33rd, 41st) derived from the production and consumption of livestock products are projected to increase significantly. Figure 6 shows that the Nitrogen Emission Intensity levels (NEI^P, Table 3, 51st) caused by livestock production in the 3H region exceed the environmental capacity (Table 1, 55th). The highest recorded NEI^P value for livestock production in Beijing was 309 kg N/ha·y in 2006, which happened because the "Vegetable Basket" project (MOA-PRC 1995) to strengthen the capacity to supply livestock products resulted in significant nitrogen emissions from animal manure. This figure is 2.9 times higher than the national average [107 kg N/ha·y] (Wang et al. 2006) and 1.8 times higher than the safe threshold. The NEI^P of livestock in Beijing will decrease by 6% to 215 kg N/ha·y by 2020, which is less than the level of 228 kg N/ha·y recorded in 2010. The reasons for the changes in NEI^P are as follows. Since 2006, regulations on nitrogen emissions have been gradually strengthened (MEP-PRC 2007). In addition, an increase in the feed price triggered a rise in production costs, such as corn expenditure. These circumstances have directly affected farmers' incomes in metropolises such as Beijing, and greatly reduced their enthusiasm. Consequently, it is expected that the amount of livestock production there will decline to 10.8 kiloton of nitrogen by 2020, equivalent to 75% of the 2005 value. Conversely, increases in the NEI^P of livestock by 2020 are projected for Tianjin (increase of 40% compared to the 2010 value), Hebei (increase of 30%), Henan (increase of 20%), and Shandong (increase of 11%), which suggests significant pressure in peripheral areas due to weak production in Beijing. We also found that the Nitrogen Emission Intensity (NEI^C, Table 3, 52nd) caused by human manure and kitchen waste in Beijing, Tianjin, Hebei, Shandong, and Henan will increase by 1.9, 1.9, 1.9, 1.5, and 1.5 times, respectively, compared with 2010. The relative values of NEI^C (Table 3, 52nd) against NEI^P (Table 3, 51st) in 2020 will reach 1.02, 0.34, 0.19, 0.18, and 0.15, and increase by 0.5, 0.06, 0.07, 0.04, and 0.02 compared with 2010, respectively. Thus, the water environment in the 3H region is facing dual pressures from nitrogen emissions caused by livestock production and consumption. Particularly in Beijing, the abundant nitrogen emissions caused by the intensive consumption of livestock products are prompting equal concern to those of livestock production.

A quantitative analysis was performed to verify the environmental impact of nitrogen emissions related to the production and consumption of livestock products; the results of which are shown in Figure 7. Environmental policy and market mechanisms influence the projected values. The projected 2020 Environmental Impact Intensity caused by livestock production (EII^P, Table 3, 53rd) for the most developed area (Beijing) represents decreases of 24 and 6% compared with the 2005 and 2010 values, respectively. This value approaches the 2020 level recorded in Henan, and corresponds to level IV of the EII. However, the EII^P in

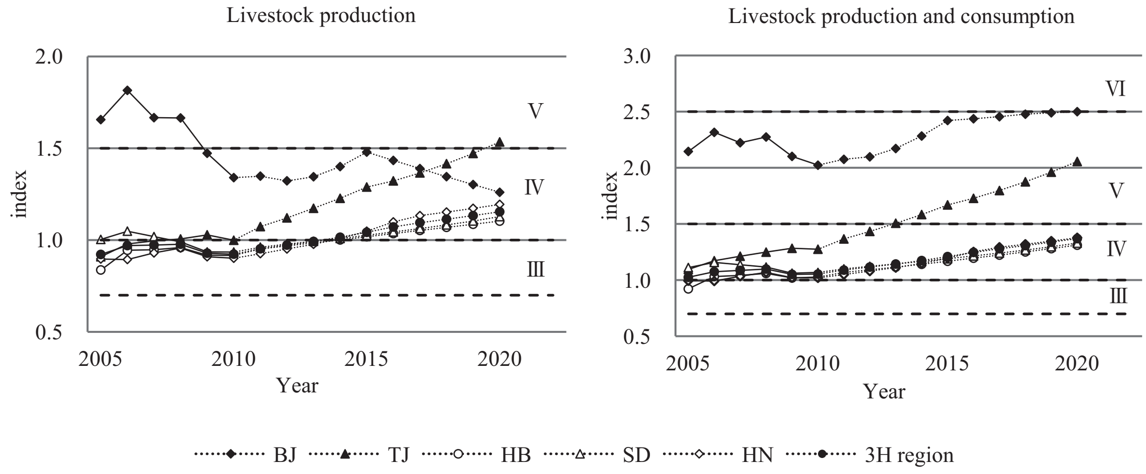

Fig. 7. Environmental Impact Intensity caused by livestock production and consumption
Note: The horizontal dashed lines indicate index levels for the EII (EII^{PC}, Table 3, 54th).

Tianjin, Hebei, Shandong, and Henan is caused by livestock production increased of 54, 20, 21, and 33%, respectively. The EII^{P} in Tianjin corresponds to level V of the EII, and corresponds to level IV in the other three areas. The increase in nitrogen emissions caused by consumption growth will also intensify environmental disruption within each region. The Environmental Impact Intensity caused by livestock production and consumption (EII^{PC}, Table 3, 54th) projections for the year 2020 show that Beijing will have the highest value of 2.5 (pollution levels of serious concern). Tianjin will be in the second place with a value of 2.1 (pollution levels of serious concern), whereas Henan will be in third place, with a value of 1.4 (pollution levels of slight concern). With a value of 1.3 each (pollution levels of slight concern), Hebei and Shandong will be in fourth place. Nitrogen emissions from livestock production and consumption are considered one of the major sources of environmental pollution, and will trigger increasingly severe deterioration in Beijing and Tianjin.

To date, no long-term predictions for NEI and EII in the 3H region have been published and while a quantitative analysis for 2005 exists, the results are very limited. We could not establish a detailed comparison due to the lack of specific explanatory data and parameters in a previous study (Ma 2009). However, from the characteristics of the 2005 NEI derived from livestock manure (excluding volatile loss), Beijing is most serious (more than 180 kg N/ha·y), which is about 1.5 times higher than the other areas within the 3H region. The NEIs between the other areas do not differ significantly and are within the range 100 to 118 kg N/ha·y.

4. Recycling ratios of nitrogen in livestock production and consumption

The recycling ratios of nitrogen (Table 3, 57th) from livestock products are relatively low (Table 5), while the production efficiency (Table 3, 56th) is also modest (within the range 0.06 to 0.22, excepting chicken). The nitrogen recycling ratios in many areas exhibit a decreasing trend (Fig. 8), although the nitrogen production efficiency tends to increase over time (Fig. 9). When considering the nitrogen production efficiency, it should be noted that milk and beef have higher efficiency. Furthermore, their per-capita discharges of nitrogen are also very high (Table 5), which means increased production of milk and beef will trigger higher discharges of nitrogen. Eggs and chicken have high production efficiencies, but their compost ratios are relatively low, which means increased production of eggs and chicken will have the effect of reducing nitrogen emissions under the same nitrogen production conditions. Meanwhile,

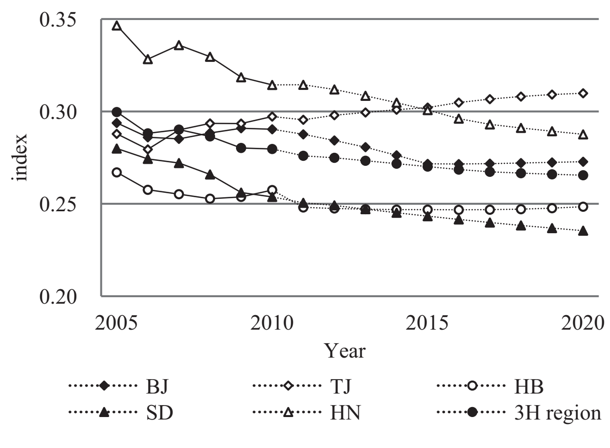

Fig. 8. Recycling ratios of nitrogen in livestock production and consumption

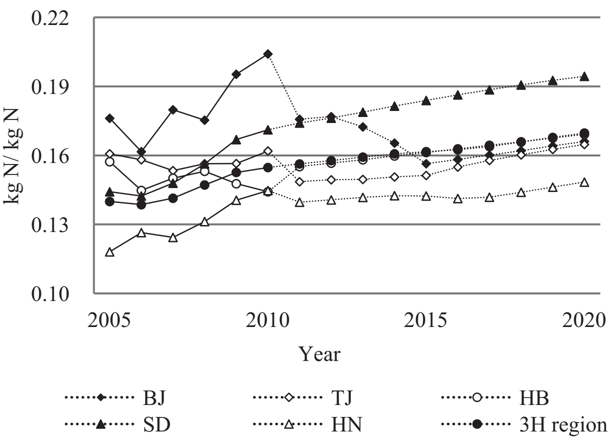

Fig. 9. Efficiency of nitrogen production for livestock products

there is a tendency for the amount of recycled nitrogen to decrease more significantly. In addition, although the manure in pig farming has a high compost ratio (Table 5), pork production efficiency for nitrogen is very low at only 0.11 due to high per-capita nitrogen emissions (Table 5). The nitrogen production share of chicken is the largest (Fig. 5), but has the lowest recycling ratio. Pork and mutton have lower production efficiencies and higher output levels of nitrogen. There is a declining tendency in pork and mutton due to the sustained growth of nitrogen from milk and chicken, which have high production efficiencies. Population growth and income increases will prompt the rapid expansion of livestock product consumption. Due to such rapid increases in waste from the household consumption of livestock products, and expensive disposal costs for organic nitrogen, the recycling ratio of nitrogen tends to gradually decline in the region.

Conclusion

This study proposed an integrated projection methodology and generated useful data to help develop the livestock sector in China sustainably. To analyze dynamic changes and derive accurate projections, we constructed a comprehensive set of models comprising food supply-demand-, nitrogen balance-, and environmental evaluation models. This study focused on analyzing medium- and long-term projections and the environmental impacts resulting from the demand-supply of nitrogen nutrients from livestock products in the 3H region.

In conclusion, there is an opportunity for regional self-sufficiency with respect to nitrogen derived from the total livestock production in the region and achieving self-sufficiency for beef, pork, and mutton within the 3H region would be a challenge. To solve these problems, the normal solution involves purchasing from elsewhere or expanding production. However, such economic activity will undoubtedly trigger greater pressures on other areas and the environment. Meanwhile, the increases in NEI^{PC} related to production and consumption will result in environmental deterioration. Projections extending to the year 2020 indicate that the EII^{PC} in the 3H region will correspond to pollution level IV (pollution levels of slight concern). Beijing and Tianjin are the areas most seriously affected, with pollution levels exceeding category V (pollution levels of serious concern). In addition, the projection results show that the nitrogen recycling ratios in the 3H region will decline. To fundamentally improve the state of the environment and food security, multiple approaches and integrated measures are required, extending from the management of livestock production as the starting point, and covering the control of product consumption as well as regional nitrogen resources and environmental management. For development plans to contribute to local economies, it is important to ensure new technologies and policies are quantitatively evaluated using the indicators.

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