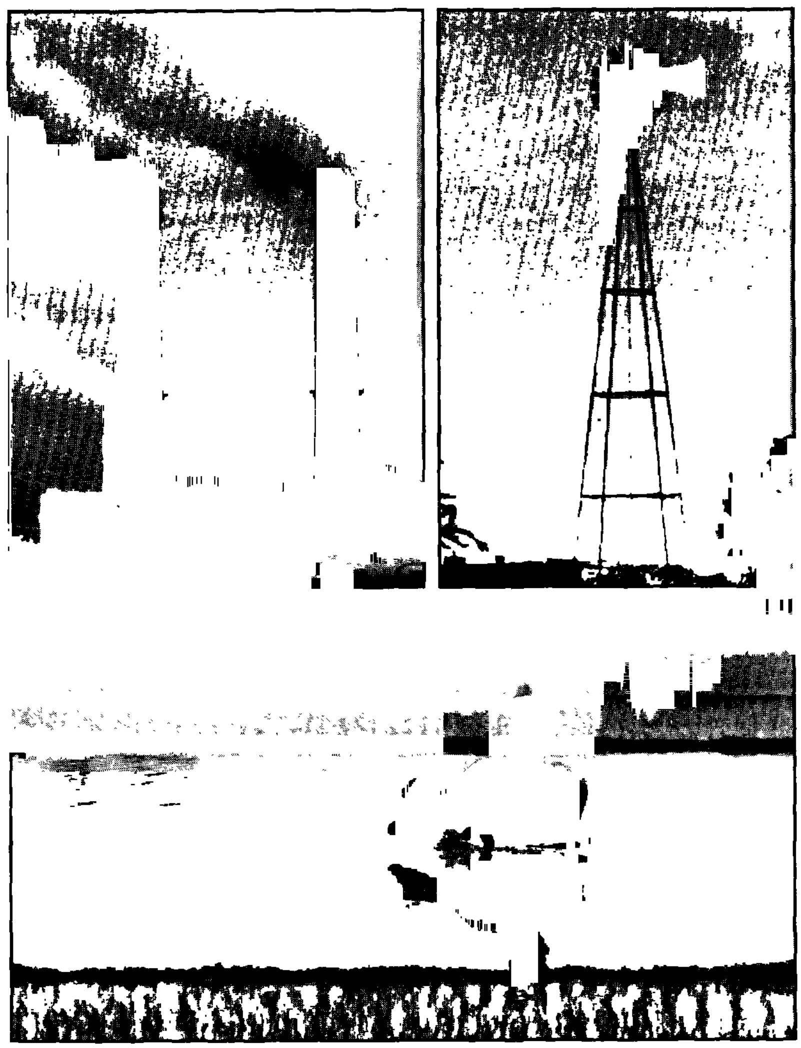
CHINA

Issues and Options in Greenhouse Gas Control



GREENHOUSE GAS CONTROL IN THE AGRICULTURAL SECTOR

SUBREPORT NUMBER 7

Zhang Yaomin, Gary J. Wells, Duan Wude, Zhang Hongsheng,
Zhou Yi, Sheng Yue, Duan Zuoliang, Zhang Dafang, and Li Bo

September 1994

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Foreword

This report is one of eleven subreports prepared by Chinese and international experts as inputs to the United Nations Development Programme technical assistance study, China: Issues and Options in Greenhouse Gas Emissions Control.

Overall management for this subreport was the Chinese National Environmental Protection Agency (NEPA), with the project research organized by the Department of Environment and Energy, Ministry of Agriculture. Key inputs for the study were provided by the Institute of Environmental Protection and Monitoring, Ministry of Agriculture, Tianjin, China. The authors of the report were Zhang Yaomin, Duan Wude, Zhang Hongsheng, Zhou Yi, Sheng Yue, Duan Zuoliang, Zhang Dafang, and Li Bo. Economic analysis of the case studies, details of which are provided in the Annexes, were done by Gary Wells, Department of Agricultural and Applied Economics, Clemson University. Editoral Assistance was provided by Kathlin Smith and Todd M. Johnson.

CURRENCY EQUIVALENTS

1 US$ = 4.7 Chinese Yuan (1990)

WEIGHTS AND MEASURES

tce = ton coal equivalent = 7 x 10^6 kilocalories
ton of coal = 0.7143 tce, average
Tg = Million tons
Carbon (C) = 12/44 x carbon dioxide
hectare = 10^4 m^2 = 2.47 acres

ABBREVIATIONS AND ACRONYMS

C	-	Carbon
CH_4	-	Methane
CMA	-	Chinese Ministry of Agriculture
CO_2	-	Carbon dioxide
EIRR	-	Economic internal rate of return
FSAI	-	Frozen semen artificial insemination
GEF	-	Global Environment Facility
GHG	-	Greenhouse gas
IAP	-	Institute of Atmospheric Physics, Chinese Academy of Science
IPCC	-	Intergovernmental Panel on Climate Change
kgce	-	Kilogram of coal equivalent
mtce	-	Million tons of coal equivalent
N	-	Nitrogen
N_2O	-	Nitrous oxide
NEPA	-	National Environmental Protection Agency of China
NPV	-	Net present value
OECD	-	Organization of Economic Cooperation and Development
SSTC	-	Stae Science and Technology Commission
t	-	Metric ton
tce	-	Ton of coal equivalent
Tg	-	Teragram
UNDP	-	United Nations Development Programme

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EXECUTIVE SUMMARY

i. This report concerns the agriculturally related emissions of two greenhouse gases, methane (CH_4) and nitrous oxide (N_2O), in the People's Republic of China. Rice paddies, domesticated animals and their waste, and crop residue burning are the sources of CH_4 considered, while fertilizer applications and crop residue burning are considered as sources of N_2O.

ii. The report is presented in three sections. The first section estimates China's emissions of CH_4 and N_2O in 1988 and 1990 from the sources noted above. The second summarizes Chinese research aimed at reducing emissions. Finally, projections of emissions levels to the year 2020 are made.

Estimates of CH_4 and N_2O from Agricultural Sources

iii. The Intergovernmental Panel on Climate Change (IPCC) has established guidelines for estimating anthropogenic greenhouse gas emissions from agricultural sources. These guidelines were used with research results and data from China to estimate the emissions levels of CH_4 and N_2O in 1988 and 1990. The results are provided in Table 1. For rice harvests, fertilizer consumption, and crop residue burning, the value for 1988 is an average of values in 1987 and 1989.

iv. For rice paddies, the estimated daily emissions flux of 0.19 to 0.69 g CH_4/m^2 found in research conducted in Hangzhou was used to calculate the Table 1 values. This wide range is typical of research findings for rice paddy emissions elsewhere in the world.

v. To estimate animal emissions, the IPCC method requires classification of animals by category. A representative, or typical, animal is then adopted for each category. Emissions estimates (Table 1) are based on these representative animals and the population of animals in each category. Domesticated animals were classified into the following groups: yellow cattle, buffalo, yaks, dairy cattle, camels, horses, mules, donkeys, swine, and sheep and goats. Ruminants are the primary animal source of methane, accounting for 95 percent of CH_4 emissions by domesticated animals.

vi. The potential methane emission from animal waste is quite high, but only 10 percent of this potential is realized. Actual emissions depend on the type of waste and the waste management system. Management systems that allow anaerobic decomposition have the highest potential for emissions. These systems include slurries, biogas generators, and application on flooded rice fields. The estimates in Table 1 take into account management systems as well as the type and quantity of animal waste.

Table 1: CH_4 AND N_2O EMISSIONS FROM AGRICULTURAL SOURCES IN CHINA, 1988 AND 1990

	CH_4 emissions Tg 1988	*CH_4 emissions Tg 1990*
Rice fields	5.6 - 22.6	5.7 - 23.0
Domestic animals	6.31	6.61
Animal waste	1.93	2.03
Residue burned	0.787 - 1.462	0.881 - 1.636
	N_2O Emissions Tg 1988	*N_2O Emissions Tg 1990*
Fertilizer range	0.0029 - 1.63	0.0019 - 1.90
Fertilizer median	0.033	0.033
Residue burned	0.0074 - 0.0265	0.0082 - 0.0297

vii. N_2O is produced naturally in soil through nitrification and denitrification. The use of nitrogen fertilizer can enhance this emission, and different fertilizers enhance emissions to varying degrees. Because of data limitations, Table 1 estimates only aqua ammonia, other nitrogen fertilizers, and complex fertilizers. "Other" nitrogen fertilizers include urea, ammonium bicarbonate, and ammonium sulfate. Aqua ammonia consumption has been declining at a rate of 17 percent per year, but the increased use of other fertilizers has boosted overall consumption of nitrogen fertilizers by an average of 8.6 percent annually.

viii. Crop residue burning is a source of both CH_4 and N_2O emissions. The main sources of residues are rice and wheat straw; others sources are corn stalks and cobs, and crop-processing residues (e.g., bagasse). Residue production was estimated from crop production data and a residue/crop ratio. About 60 percent of this residue is burned either as fuel or on the field. Using IPCC methodology, the carbon content and resulting CH_4 and N_2O emissions were estimated. CO_2, the primary greenhouse gas emission from crop residue burning, is ignored because it is assumed that the crop is replanted, recapturing the CO_2 that was released.

Chinese Research on Emissions Reduction

Semidry Cultivation of Rice

ix. Semidry rice cultivation involves creating furrows which are then flooded two-thirds full. Rice is transplanted on the ridge, promoting development of the root system. This technique of partial flooding reduces the likelihood of anaerobic decomposition of organic material, of which methane is a by-product.

x. A pilot project for semidry cultivation was begun in 1982 in Sichuan Province and was introduced in southern China between 1985 and 1988. By 1988, 674,000 hectares (2 percent of China's rice growing area) was cultivated in this manner. The technique is now being combined with fish farming and the interplanting of aquatic vegetables and medicinal plants to further raise rural incomes.

xi. A three-year study by the Nanjing Institute of Environmental Protection, under China's National Environmental Protection Agency (NEPA), found that the semidry rice cultivation system reduced CH_4 emissions by 31-43 percent. However, because this system of cropping requires intensive soil preparation and water management, and is possible only on certain types of terrain, Chinese agricultural experts estimate that it will be used on only 15-25 percent of China's rice-growing area by 2020, and this will be possible only with government support.

Intermittent Irrigation of Paddy Fields

xii. Rice shoots do not have to live in water all the time. At certain times rice requires flooding, while at other times the field can be allowed to dry to promote soil ventilation. The appropriate timing of moist versus dry periods can improve productivity and reduce methane emissions. Methanogenic bacteria decompose organic material under anaerobic conditions. Prolonged flooding enables peak anaerobic activity. By shortening the period of flooding, the conditions for growth of methanogens are disrupted and methane production is suppressed.

xiii. Field studies throughout the world have found that methane emission rates vary greatly depending on field location and time of year. Chinese studies support this finding. Emissions from flood-irrigated fields ranged from a low of 8.5 $mg/m^2.h$ to a high of 35.9 $mg/m^2.h$. Field trials of intermittent irrigation near Beijing found emissions reductions of 12 to 59 percent, and, in all but one trial, rice output was slightly higher with intermittent irrigation.

xiv. In recent years, this production technology has been widely adopted in the high-yield rice-growing areas of China, but there are limits to its adoption. Regions with water shortages and low-lying land that is slow to drain cannot benefit from it. As a result, it is estimated that by 2020 intermittent irrigation will account for no more than 15 percent of rice production in China.

Fertilizer Application

xv. As stated earlier, organic waste is often used as fertilizer. The disposal method of this organic material determines the potential for methane emissions. For example, leaving the waste in the pasture or spreading it daily minimizes the potential for methane production. On the other hand, disposal in a flooded rice paddy creates the anaerobic environment necessary for methane production. The potential for methane production from using animal waste on flooded rice paddies can be cut by 40 to 60 percent by aerobic composting before application.

xvi. Another possible treatment of organic waste material is anaerobic digestion (biogas production). This treatment produces methane that can be collected as an energy source and a residue that can be used as a fertilizer. Research sponsored by the Chinese Ministry of Agriculture compared the use of this treated organic material to the use of untreated organic waste and chemical fertilizers in rice fields. It found that application of anaerobically treated fertilizer resulted in an emissions flux averaging 30 percent less than that from untreated organic fertilizers, and 21 percent less than that from chemical fertilizers.

xvii. The use of chemical or inorganic fertilizers such as ammonium sulfate or urea may help decrease CH_4 emissions from flooded rice fields by as much as 40 percent when compared with organic fertilization. Inorganic fertilizers, however, enhance N_2O emissions.

Breed Improvement

xviii. In 1978, the State Scientific and Technological Commission (SSTC) decided that artificial insemination (AI) should be adopted to introduce improved foreign and domestic breeds through crossbreeding. In 1980, 140 bulls were imported from North America and Western Europe for use in the program.

xix. In addition to allowing producers to select breeds, artificial insemination avoids many of the shortcomings of natural service. For example, AI can prevent premature mating, allow a breeding date be fixed, and increase the conception rate. Another advantage of frozen semen artificial insemination (FSAI) is its ease of mastery. With about 15 days' training, a veterinarian can master the skill and produce a conception rate of 50 to 85 percent. The FSAI program has become more efficient as it has matured. For example, consumption of liquid nitrogen, used to freeze semen, has declined from 0.47 cubic liters per head to 0.19 cubic liters per head. Also, semen cell consumption has declined from 3.8 cells per head to 2.5 cells per head.

xx. From a commercial beef producer's point of view, the FSAI program has been a success. Case study results indicate a 74 percent financial rate of return from using improved cattle over domestic yellow cattle. Sensitivity analysis given alternative weight gain and feed consumption levels indicates stable results. Improvement of cattle by way of FSAI crossbreeding has four main advantages: it increases the usable carcass weight, increases the fertility rate, reduces the number of bulls needed, and increases individual productivity. All of these qualities help to reduce CH_4 emissions per kilogram of product. There is the potential to reduce methane emission by almost 11 percent per animal. With cattle numbers predicted to increase from 100 million in 1988-90 to almost 169 million by 2010, the impact on methane emissions could be substantial.

Ammoniated Feed

xxi. In the early 1980s, China introduced a pilot program to use ammoniated straw to feed cattle. Straw and stalks are ammoniated by cutting them to 2-3 cm lengths and mixing them with urea and water; the mixture is then fermented. Ammoniated straw is estimated to contain twice to three times the amount of crude protein found in the raw product. Moreover, the amount consumed and speed of digestion increase by 20 percent. Despite a slow start, the program has recently expanded rapidly. In 1986, only 43,000 tons of straw were ammoniated; in 1991, the amount had grown to 3.71 million tons, an 86-fold increase. This rapid adoption is attributable to low investment costs, high financial returns, and the simplicity of the technique.

xxii. Enhanced weight gain is a primary factor in the increased financial returns. Research at the Hebei Animal Husbandry Research Institute found that daily weight gain averaged 644 grams when treated straw was used versus 348 grams when it was not—an 85 percent improvement. Using these weight gain differentials, a financial rate of return of 110 percent resulted when a hypothetical project feeding ammoniated straw was compared with a similar project feeding untreated straw.

xxiii. Ammoniation also affects methane emissions. Although improved diet and increased feed consumption result in increased daily methane emissions from each animal, emissions on a per-kilogram weight gain basis decline by 38.5 percent. Given that China's beef production and consumption are predicted to continue their rapid increase, this is an important consideration. Based on the current rate of development, it is likely that, by 2020, approximately 20 percent of the feed used in cattle raising will be ammoniated. Shortages of urea, a key ingredient in the ammoniation process, and cotton seed cake, a supplement that improves feed efficiency, might pose obstacles to adoption in some areas.

Rural Energy

xxiv. In 1990, 583 million tons of coal equivalent were consumed in rural China, 2.5 times the level in 1980. The commercial sector, which relies on nonbiological energy sources, was primarily responsible for this increased consumption. Nonetheless, 50.6 percent of the energy consumed in 1990 came from biological energy sources such as crop residue burning.

xxv. If emissions from activities such as crop burning for fuel are to be reduced, the energy consumption patterns of farmers and other rural residents have to change. Greater use of energy-saving wood and coal stoves and *kangs*,1/ family-sized biogas generating ponds, and solar water heaters and cookers could assist in this change. It is estimated that by 2020, biological energy use (e.g., plant straw, animal dung, and wood) will decline by 10 to 20 percent, while overall rural energy use will increase.

Projections of Emissions Levels to the Year 2020

xxvi. Greenhouse gas emissions levels were predicted for the following agricultural sources: paddy fields, nitrogen fertilizer applications, cattle production, and

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1/ A *kang* is an elevated bed with a heating system.

straw burning. Projections were made for 2000, 2010, and 2020, and were compared with 1990 levels. For each source a high, medium, and low emissions scenario was constructed.

xxvii. Methane emission predictions from rice production are shown in Table 2. These predictions are based on estimates of planted rice area and alternative adoption rates of semidry and intermittent irrigation management techniques. A linear differential equation model was used to estimate area as a function of time. The rates of adoption by the year 2020 are assumed as follows:

Scenario	Intermittent irrigation	Semidry
High	1990 levels	1990 levels
Medium	10%	15%
Low	15%	25%

Table 2: PREDICTED PADDY FIELD CH_4 EMISSIONS (Tg/yr)

	1990		2000	
	Median	Range	Median	Range
High	14.40	5.7-23.1	15.1	6.01-24.19
Medium	14.40	5.7-23.1	14.45	5.62-23.28
Low	14.40	5.7-23.1	14.04	5.38-22.71

	2010		2020	
	Median	Range	Median	Range
High	16.10	6.41-25.79	17.33	6.90-27.75
Medium	14.72	5.58-23.86	15.00	5.51-24.48
Low	13.85	5.07-22.64	13.61	4.67-22.56

xxviii. Predictions of N_2O emissions from fertilizer application are shown in Table 3. These predictions are based on individual projections of aqua ammonia and other nitrogen fertilizers. A linear differential equation model of fertilizer use was coupled with alternative fertilizer utilization rates to generate the high, medium, and low scenarios in Table 3. The assumed utilization rates are the current level (35 percent), 50 percent, and

60 percent. China's current fertilizer utilization rate is far below that of developed countries.

Table 3: PREDICTED N_2O EMISSIONS FROM FERTILIZER (TG)

	1990		2000	
	Median	Range	Median	Range
High	0.020	0.0014 - 1.11	0.0033	0.00072 - 2.003
Medium	0.020	0.0014 - 1.11	0.0030	0.00067 - 1.849
Low	0.020	0.0014 - 1.11	0.0025	0.00056 - 1.541
	2010		**2020**	
	Median	Range	Median	Range
High	0.059	0.00068 - 3.638	0.106	0.0010 - 6.615
Medium	0.050	0.00058 - 3.078	0.082	0.00078 - 5.089
Low	0.066	0.00047 - 2.519	0.066	0.00063 - 4.071

xxix. Currently, cattle are the largest contributors to methane emissions among livestock, accounting for 46.75 percent of the total. Predictions of methane emissions from cattle are given in Table 4. These predictions are based on cattle numbers estimated by the Chinese Ministry of Agriculture, and alternative adoption rates of breed improvement and use of ammoniated feed. The estimated cattle population is based on demand projections, while the high, medium, and low emissions scenarios are based on the following assumed adoption rates:

	2000	2010	2020
High	1990 rates	1990 rates	1990 rates
Medium			
Breed improvement	30%	50%	70%
Ammoniated feed	10%	15%	20%
Low			
Breed improvement	40%	70%	90%
Ammoniated feed	15%	20%	25%

Table 4: PREDICTED CH_4 EMISSIONS OF CATTLE (TG)

Scenario	1990	2000	2010	2020
High	4.832	7.290	10.326	14.542
Medium	4.832	5.968	7.032	7.998
Low	4.832	5.418	5.679	6.094

xxx. Predicted methane emissions for straw burning are shown in Table 5 and nitrous oxide emissions for straw burning are shown in Table 6. These estimates are made by first estimating crop production and then estimating the percentage of the straw that will be burned.

xxxi. A linear differential equation model is used to estimate production of rice, wheat, tubers, maize, sorghum, millet, other grains, and soybeans. The resulting estimates are adjusted by governmental production targets. The high, medium, and low emissions scenarios assume burning rates of 60 percent (the current burning rate), 50 percent, and 40 percent. Burning rates are expected to decline as other energy sources are substituted for crop residue burning. Hence, the lower scenarios are more plausible than the high.

Table 5: PREDICTED CH_4 EMISSIONS OF STRAW BURNING (Tg)

Scenario	1990	2000	2010	2020
High	0.88-1.64	0.96-1.78	1.12- 2.11	1.38 - 2.57
Medium	0.88-1.64	0.91-1.69	1.03-1.90	1.15 - 2.14
Low	0.88-1.64	0.86-1.60	0.89-1.65	0.92 - 1.71

Table 6: PREDICTED N_2O EMISSIONS OF STRAW BURNING (TG)

Scenario	1990	2000	2010	2020
High	0.0082-0.030	0.0089-0.034	0.011-0.041	.013-0.047
Medium	0.0082-0.030	0.0085-0.031	0.0096-0.035	.011-0.039
Low	0.0082-0.030	0.0081-0.029	0.0083-0.030	.0086-0.031

1. INTRODUCTION

1.1 The potential for anthropogenic contributions to global warming has prompted creation of the Global Environmental Facility (GEF) and its resulting investigation of how to reduce greenhouse gas (GHG) emissions. This report presents the agricultural portion of the GEF China project entitled "Issues and Options in Greenhouse Gas Emissions Control."

1.2 China's agricultural sector is a major contributor to its GHG emissions. In 1986, rice and animal production accounted for almost 20 percent of China's total CO_2-equivalent emissions, while biomass burning accounted for nearly an additional 7 percent (preliminary estimates by World Bank staff). As a major contributor, agriculture warrants careful consideration as a possible control point for GHG emissions. Hence, the objective of this study will be to determine the current status of GHG emissions and the potential to influence emissions through changes in production practices.

1.3 Methane and nitrous oxide are the greenhouse gases that will be considered.2/ Agricultural activities are a major anthropogenic source of these gases. This is particularly the case for methane, which on a 100-year horizon is 21 times more potent than carbon dioxide as a GHG. Rice cultivation contributes about 20 percent of the global methane emissions and animal husbandry (through animals and their waste) contributes another 20 percent (World Bank). The only other methane source that rivals these is natural wetlands—a nonanthropogenic source. Methane's contribution to the potential for global climate forcing during the decade of the 1980s was 15 percent (Drabenstott p. 8). Hence, curbing methane emissions is important to GEF strategies.

1.4 Nitrous oxide is 290 times more potent as a GHG than CO_2, but because of a relatively small volume in the atmosphere it is a much smaller total contributor to the potential for global climate change.3/ During the 1980s, N_2O contributed only 6 percent. Moreover, carbon dioxide and methane concentrations are both expected to grow by more than 80 percent from 1986 to 2100, while nitrous oxide is expected to increase only 12 percent (Nordhaus). What makes nitrous oxide important from the GEF's

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2/ Carbon dioxide is also emitted, especially as a result of biomass burning. Biomass is burned primarily for fuel. The alternative to burning biomass as a fuel is use of fossil fuels. Hence, it is not anticipated that reduction of biomass burning would yield much of a change in CO_2 emissions. As a result, CO_2 emissions will not be taken into consideration in this report. Non-CO_2 emissions from biomass burning will, however, be presented. The 7 percent figure cited above is this non-CO_2 component from biomass burning.

3/ In 1986, N_2O's atmospheric concentration was 340 parts per billion (ppb) while methane's was 1,675 ppb and CO_2 was 348 ppm.

point of view is its potency. Reducing the 6 percent it contributes may offer some of the most cost-effective treatment of the potential for global warming.

1.5 The sources of N_2O considered are fertilizer applications and crop residue burning. The sources of methane considered are rice paddies, domesticated animals and their waste, and crop residue burning. The main body of the report is presented in three sections. The first section estimates China's 1988 and 1990 emissions of CH_4 and N_2O from the above sources. The second summarizes Chinese research aimed at reducing emissions, and the final section presents agriculturally related emissions projections to the year 2020. These projections take into consideration the likely adoption of emissions-reducing practices.

1.6 Two case studies are provided in the appendices. The first study investigates the financial and economic feasibility of breed improvement programs. Improved breeds emit less methane per kilogram of meat produced. The second study investigates the financial and economic feasibility of using ammoniated straw as an animal feed. This feed is higher in nutrient value and thus results in faster weight gains in cattle, again reducing methane emissions per kilogram of weight gain.

1.7 The study of China's greenhouse gas emissions has focused on the methane emissions of paddy fields and ruminant animals. Since 1985, institutions throughout China have conducted studies on paddy field emissions. However, fewer studies have been done on ruminant animal emissions.

1.8 In the late 1980s, researchers from the Chinese Academy of Sciences' Institute of Atmospheric Physics (IAP) began cooperating with researchers from the United States and Germany. Together, they undertook the first measurements of methane emissions from paddy fields near Leshan, Sichuan Province, and Hangzhou.

1.9 From 1990 to 1992, China's National Environmental Protection Agency (NEPA) cooperated with the U.S. Environmental Protection Agency in measuring the methane emissions of paddy fields in Nanjing and Beijing. Participants included the Nanjing Environmental Protection Institute (under NEPA), the Institute of Atmospheric Physics, Peking University, and the Chinese Academy of Agricultural Sciences (CAAS).

1.10 In 1992, the Chinese Ministry of Agriculture (CMA) conducted on-site measurements of paddy field methane emissions at the Hangu area of Tianjin. The results of these efforts, along with those from Leshan, Hangzhou, Nanjing, and Beijing, are shown in Table 1.1.

1.11 Since China's research on methane emissions of ruminant animals is relatively recent, experimental data are incomplete. In 1987, the Ministry of Agriculture's Institute of Gansu Grassland Ecology and Colorado State University initiated a study on the methane emissions of China's ruminant animals. Results showed that there were 72 million cattle in China at that time whose combined methane emissions were 3.6 Tg/yr.

Table 1.1: CH_4 EMISSION FLUX IN PADDY FIELDS (REGULAR CULTIVATION)

Place	Rice	CH_4 emissions flux $mg/m^2.h$	Source
Leshan	Single crop	58	Khalil, M.A.K. et al. (1991)
Hangzhou	Early	7.8	Wang Ming Xing et al. (1990)
Hangzhou	Double late	28.6	Wang Ming Xing et al. (1990)
Nanjing	Double late	10.83	Li Depo et al. (1993)
Nanjing	Double late	25.18	Li Depo et al. (1993)
Nanjing	Double late	19.85	Li Depo et al. (1993)
Beijing	Single crop	17.5	Chen Zhongliang et al. (1993)
Beijing	Single crop	20.4	Chen Zhongliang et al. (1993)
Beijing	Single crop	15.0	Chen Zhongliang et al. (1993)
Tianjin	Single crop	8.81	Tao Zhan et al. (1993)
Tianjin	Single crop	10.26	Tao Zhan et al. (1993)

A subsequent study conducted by China's State Science and Technology Commission (SSTC) estimated the methane emissions of China's ruminant animals at 5.5 Tg/yr.

1.12 The CAS Research Center for Ecological Environment measured the N_2O emissions of soil typical of the winter wheat fields in northern China near Shijiazhuang, Hebei Province. Results showed the average flux range of N_2O emissions from the soil is 6-45 μg N_2O-$N/m^2.h$.

1.13 To evaluate the effects of greenhouse gases on climate change more accurately, the SSTC included as part of its technical key tasks for the Eighth Five-Year Plan a project to predict global climate changes and their impacts, and to propose solutions. The IAP and other institutes were given responsibility for measuring greenhouse gas emissions by agricultural sources.

1.14 These efforts will serve as the starting point for estimates of agriculturally related emissions of CH_4 and N_2O. Other work done independently of this report will also be cited. Finally, the study will be completed with research done for the current effort.

2. ESTIMATION OF CH_4 AND N_2O EMISSIONS FROM AGRICULTURAL SOURCES

A. ESTIMATION OF CH_4 EMISSIONS FROM PADDY FIELDS

2.1 China claims 22 percent of the world's rice-growing area and is second only to India in rice production. Rice cultivation in China can be classified into southern and northern regions. In the south, rice is double-cropped. The area sown for various crops between 1987 and 1990 is shown in Table 2.1.

Table 2.1: AREA OF SOWN RICE, 1987-90
(1,000 ha)

Rice type	1987	1988	1989	1990	1987-1989 avg.
Early	9,370	9,220	9,365	9,418	9,318
Intermediate	10,528	10,678	10,888	10,984	10,698
Double late	9,768	9,558	9,776	9,839	9,701
Single	2,527	2,532	2,672	2,824	2,577
Total	32,193	31,988	32,701	33,065	32,294

Source: *China Agricultural Yearbook 1988-91.*

2.2 Methane emissions from paddy fields in Hangzhou were calculated on the basis of a daily emissions flux of 0.19-0.69 g CH_4/m^2. Because traditional rice cultivation entails transplanting instead of direct seeding, the growing period is calculated according to the number of days from transplanting to harvesting. The growing periods for various types of rice in China are shown in Table 2.2.

2.3 In Table 2.3, a three-year average for harvests (1987-89) was used to calculate methane emissions for 1988, while the calculation for 1990 is based on the actual harvest yield for that year. From 1988 to 1990, the average level of paddy field emissions increased 0.2 Tg, or 1.4 percent.

Table 2.2: GROWING DAYS OF RICE, BY VARIETY

			Mid-season variety	
			Sowing-harvesting	Transplanting-harvesting
Southern rice region	Indian type rice	ER	110-120	80-90
		IR	130-140	100-110
		DL	120-130	80-90
	Nonglutinous	DL	120-130	90-100
Northern rice region	Nonglutinous	SR	130-150	95-110

Source: Mei Fangquan et al. 1987. *Study on Regionalization of Rice Cultivation in China*, pp. 17-30. Beijing: Science Press.

Table 2.3: CH_4 EMISSION FROM PADDY FIELDS IN CHINA, 1988 AND 1990

	1988/a		1990	
Rice type	CH_4 emission TG/yr CH_4	CH_4-C emission TG/yr CH_4	CH_4 emission TG/yr CH_4	CH_4-C emission TG/yr CH_4
ER	1.4-5.8	1.1-4.3	1.4-5.8	1.1-4.4
IR	2.0-8.1	1.5-6.1	2.1-8.3	1.6-6.2
DL	1.7-6.7	1.2-5.0	1.7-6.8	1.3-5.1
SR	0.5-2.0	0.3-1.5	0.5-2.1	0.4-1.6
Total	5.6-22.6	4.1-16.9	5.7-23.0	4.3-17.3

/a Average value of 1987-89.

Source: *China Agricultural Yearbook 1988-1991* and IPCC Report, pp. 5-50, Table 5-9. Calculation method: "Estimation of Greenhouse Gas Emissions and Sinks," Final Report from the OECD Experts Meeting, 18-21 February 1991, prepared for the IPCC, August 1991, pp. 5-47.

B. ESTIMATION OF N_2O EMISSIONS FROM NITROGEN FERTILIZER USE

2.4 Nitrous oxide is produced naturally in soil by nitrification and denitrification. Nitrogen fertilizer use can increase this emission. Statistics on China's nitrogen fertilizer consumption are provided in Table 2.4.

2.5 Because of data limitations, China's nitrogen fertilizer consumption cannot be classified in detail; it has been separated generally into aqua ammonia, other nitrogen fertilizers, and complex fertilizers. Other nitrogen fertilizers include urea, ammonium bicarbonate, and ammonium sulfate.

Table 2.4: ANNUAL NITROGEN FERTILIZER CONSUMPTION IN CHINA (1987-90)

Fertilizer type	Amount consumed (10^3 tons N) 1987	1988	1989	1990	1987-89 average	Annual increase (%)
Aqua ammonia	240	176	174	118	197	-17.0
Other nitrogen fertilizer	13,028	13,995	15,187	16,259	14,070	8.3
Complex fertilizer	754	881	1,014	1,275	883	23.0
Total	14,022	15,052	16,375	17,652	15,150	8.6

Source: *China Agricultural Yearbook (1988-91).*

2.6 Table 2.4 shows that over three years, aqua ammonia consumption decreased at an average annual rate of 17 percent. Meanwhile, consumption of other nitrogen fertilizers and complex fertilizers increased at an annual rate of 8.3 percent and 23 percent respectively. Total nitrogen fertilizer consumption increased from an estimated 14.02 million tons in 1987 to 17.65 million tons in 1990, an annual average increase of 8.6 percent.

2.7 The study concludes that nitrogen fertilizer application can affect N_2O emission. Fertilizer-derived N_2O emissions by fertilizer type are shown in Table 2.5. The average emission value of 1987-89 is the same as that in 1988 (Table 2.6). The table shows that the estimated range of N_2O emissions from nitrogen fertilizer applied in 1988 is 0.002-1.04 Tg N2O-N (0.003-1.63 Tg N2O); the median is 0.0197 Tg N2O-N (0.03 Tg N2O). The estimation range of N2O emission in 1990 is 0.001-1.21 TgN2O-N (0.002-190 Tg N2O); the median is 0.0212 Tg N2O-N (0.03 Tg N2O).

C. ESTIMATION OF METHANE EMISSIONS FROM DOMESTICATED ANIMALS

2.8 Approximately 80 percent of domesticated animal methane emissions come from ruminants. China raises more sheep and goats than any other country, and is second in the world in cattle raising.

Table 2.5: FERTILIZER-DERIVED N_2O EMISSION BY FERTILIZER TYPE

Fertilizer type	N_2O-N produced (median)	N_2O-N produced (range)
Aqua ammonia	1.63	0.86-6.84
Other nitrogen fertilizer	0.11	0.001-6.84
Complex	0.11	0.001-6.84

Table 2.6: N_2O EMISSIONS FROM FERTILIZER USE IN CHINA, 1988 /a and 1990

Fertilizer type	Amount consumed (10^3 tons N)	N_2O-N emission (10^3 tons N_2O-N) median	low	high	N_2O emission (10^3 tons N_2O) median	low	high
1988							
Aqua ammonia	197	3.2	1.7	13.5	6.4	2.7	21.2
Other nitrogen fertilizer	14,070	15.5	0.1	962.4	24.5	0.2	1,512.3
Complex fertilizer	883	1.0	0.01	60.4	1.6	0.02	94.9
Total	15,150	19.7	1.8	1,036.3	32.5	2.9	1,628.4
1990							
Aqua ammonia	118	1.9	1	8.1	3.0	1.6	12.7
Other nitrogen fertilizer	1,6259	17.9	0.2	1,112.1	28.1	0.3	1,747.6
Complex fertilizer	1,275	1.4	0.01	87.2	2.2	0.02	137.0
Total	17,652	21.2	1.2	1,207.4	33.3	1.9	1,897.3

/a Average value of 1987-89.

2.9 IPCC methodology is used to calculate the annual methane emissions of domesticated animals. First, animals are counted and categorized by species and position in the herd (Table 2.7), and one animal is selected to represent each species and position in the herd.

2.10 Next, gross energy intake (GE), megajoules (MJ) of methane produced per 100 MJ of gross energy feed intake (Ym), and methane emissions are calculated for each representative animal. Calculations are made accounting for characteristics such as weight,

Table 2.7: Animal population by Species, Type, and Herds Structure from 1988-90

Animal species & herd structure		population ('000) 1988(%)	1989(%)	1990(%)	Change rate in number 1988 increase	%	1989 increase	%	1990 increase	%
Livestock		12,531.8	12,804.8	13,021.3	346.7	2.8	267.0	2.1	216.5	1.7
Draft animal		7,219.1	7,431.9	7,606.0	196.0	1.5	212.8	2.9	174.1	2.3
	cows (fertile)	2,941.3 (39.4)	3,027.3 (39.4)	3,110 (39.6)	176.7	4.8	114.5	3	122.4	3.1
yellow	calves (<1 year)	1,328.9 (17.8)	1,367.6 (17.8)	1,387.0 (17.7)	40.3	3.0	38.7	2.8	19.6	1.4
cattle	other	3,195.7 (42.8)	3,288.3 (42.8)	3,353.1 (42.7)	110.2	3.4	92.6	2.8	64.8	1.9
	total	7,465.9	7,683.1	7,850.3	307.0	4.3	217.2	2.9	167.2	2.2
	cow(fertile)	804.2 (38.2)	822.8 (38.5)	851.5 (39.3)	18.4	2.3	18.6	2.3	28.7	3.5
buffalos	calves(<1 year)	268.1 (12.7)	271.7 (12.7)	271.3 (12.5)	0.6	0.2	3.6	1.3	-0.4	-0.15
	other(>1 year)	1034.7 (49.1)	1,044.1 (48.8)	1,046.2 (48.2)	-1.8	-0.17	9.4	0.9	2.1	0.2
	total	2,106.7	2,139.5	2,169.0	16.9	0.8	32.8	1.6	29.5	1.4
	cow (fertile)	420 (32.3)	442.3	463.1	21	5	22.3	5	20.8	5
yaks	calves	270 (20.0)	273.0	286.0	13	5	13	5	13	5
	other	620 (47.7)	651.1	683.8	30	5	31.1	5	31.7	5
	total	1,300	1,365	1,433	65	5	65	5	68.3	5
	cow(fertile)	121.2 (54.5)	131.1 (51.9)	142.1 (52.8)	5.1	4.4	9.9	8.2	11	8.4
dairy	calves	51.3 (23.1)	61.9 (24.5)	64.5 (24)	0.5	0.97	10.6	17	2.6	4.0
cattle	other	49.8 (22.4)	59.6 (23.6)	62.5 (23.2)	0.3	0.6	9.8	16.7	2.9	4.6
	total	222.2	252.6	269.1	5.8	2.7	30.4	13.7	16.5	6.5
horses	fertile	383.1	371.5	368.0	-7.4	-1.9	-11.6	0.3	-3.5	-0.9
	other	670.9	658.1	649.7						
	total	1,054.0	1,029.6	1017.1	-15.1	-1.4	-21.1	-2.3	-10.0	-1.2
donkeys	fertile jennet	427.3	425.2	429.3	5.9	1.4	-2.1	-0.5	4.1	1.0
	other	677.9	688.4	690.5						
	total	1,105.2	1,114	1,119.80	20.60	1.90	8.40	0.80	6.20	0.60
mule	total	536.6	539.10	519.40	11.80	2.20	2.50	0.50	10.30	1.90
camels	fertile camels	15.1	15.50	13.90	0.0	0.0	0.10	2.60	-1.6	-10.3
	other	32.1	32	32.4						
	total	47.2	47.5	46.3	-0.3	-0.6	0.3	0.6	-1.2	-2.5
swine	breed sow	2,519.2	2,542.6	2,521.4	319.2	14.5	23.1	0.9	-21.2	-0.8
	other									
	total	34,221.8	35,281.0	36,240.8	1,448.5	4.4	1,059.2	3.1	959.8	2.7
goats	fertile doe	4,396.0	46,598.3	1,585.0	651.3	17.4	262.3	6.0	(73.3)	(1.6)
	(dairy goats)	(225.2)	(215.6)	(208.8)	(8.2)	(3.80)	(9.60)	(4.30)	(6.80)	(3.20)
	total	9,095.6	9,813.4	9,700.5	1,326.9	17.1	717.8	7.9	(92.9)	(1.6)
	(dairy goats)	(321.8)	(325.5)	(315.0)	(21.7)	(7.2)	(3.7)	(1.1)	(10.8)	(3.2)
sheep	final wool & fertile reclaimed ewe	1,630.9	1,662.6	1676.0			31.7	1.9	13.6	0.8
	sheep total	3,224.5	3,356.2	3251.8			131.7	4.1	(104.40)	(3.50)
	half fine fertile wool & ewe	636.6	697.5	708.2			60.9	9.6	10.7	1.5
	reclaimed total sheep	1,323.5	1,412.2	1,456.2			88.7	6.7	44.0	3.1
poultry	chicken	1,849 million	1,891 million	1,984 million			42	2.2	93	4.7
	duck	325 million	333 million	363 million			8	2.4	30	8.3
	total	2,174 million	2,224 million	2,347 million			50	2.2	123	5.2

1. Statistical data for all animal except yaks. Dairy buffalos and poultry are taken from *China Agriculture Yearbook*. Poultry and dairy buffalo data from FAO yearbook. Yak data from *China Agriculture Yearbook.*
2. Herd structure is calculated from published article.
3. Based on analysis of Qinghai and Gansu Agriculture Yearbook, the population of yellow cattle in China Agriculture Yearbook would include yaks.

weight gain, milk, and draft. The GE of a fertile female is calculated, then the GE of a representative animal is estimated with consideration of GE in all size and percentiles of fertile cows, calves, and others in the herd. Representative animal methane emissions are then calculated by multiplying Ym and the conversion factor (the factor of 0.018 is used to convert MJ to kilograms of methane, using a value of 55.65 MJ/kg of methane). This value is multiplied by the number of animals in its category.

2.11 Cattle methane emissions are calculated by adding the methane emissions of yellow cattle, buffalo, yaks, and dairy cattle. Yellow cattle are divided into three categories: those from the grazing region of northern China, those from the farming region of central China, and those from the tropical and subtropical regions of southern China. Methane emissions for typical yellow cattle in China are estimated on the basis of their distribution percentage in north, central, and south China, and their productive performance. Methane emissions for buffalo, yaks, and dairy cattle are estimated by the mean productive performance of all groups.

2.12 The level of sheep and goat breeding in China is similar to that in other developing countries, so methane emissions for sheep and goats are estimated with the data (GE=BMJ, Ym=6) provided by Crutzen et al.

2.13 Nonruminant animals are less important than ruminants in terms of global methane emissions. Thus, a simple emission factor per head is sufficient. Crutzen et al. derived the following methane emission factors for developing countries:

Horses:	15 kg/head/year
Mules and donkeys:	10 kg/head/year
Swine:	1 kg/head/year

2.14 Total methane emissions from domesticated animals in China are summarized in Table 2.8.

D. Methane Emissions from Animal Wastes

2.15 The potential volume of methane emissions from animal wastes is quite high; however, typically only 10 percent of this potential is realized. Moreover, the level of methane emissions from waste is lower in China than elsewhere in the world. Methane emissions from animal wastes are estimated by first defining categories of waste types and waste management systems, then estimating the potential methane emission rate per unit of waste from each. The systems for waste handling are shown in Table 2.9. Sources of waste and the level of methane emissions from each are shown in Table 2.10. Other than the data on animal population and waste production, there are no sources that provide all of the information needed to characterize animal waste management. For this reason, US EPA data and IPCC methodology have been used to supplement the estimates.

Table 2.8: METHANE EMISSIONS FROM DOMESTICATED ANIMALS IN CHINA

Animal	Methane production /a (kg/yr/head)	Animal population (10,000 head) 1988	1990	Methane production (Tg/yr) 1988	1990
Yellow cattle	39.4	7,465.9	7,850.3	2.94	3.09
Buffalo	52.8	2,106.7	2,169.0	1.11	1.15
Yaks	31.5	1,300.0	1,433.6	0.41	0.45
Dairy cattle	53.2	222.2	269.1	0.12	0.14
Camels	58.0	47.2	46.3	0.03	0.03
Horses	18.0	1,054.0	1,017.4	0.19	0.18
Mules	10.0	536.6	549.4	0.05	0.06
Donkeys	10.0	1,105.2	1,119.8	0.11	0.11
Swine	1.0	34,220.8	36,240.8	0.34	0.36
Sheep & goats	5.0	20,152.7	21,002.0	1.01	1.05
Total	278.9	66,212.3	71,697.7	6.314	6.61

Note: Figures are derived using IPCC methodology.

/a Methane emissions for representative animal type.

Table 2.9: USE OF ANIMAL WASTE SYSTEMS IN CHINA (percent)

Animal	Anaerobic lagoon	Liquid systems	Daily spread	Solid storage & drylot	Pasture range & paddock	Used for fuel	Other system /a
Cattle	0	0	16	14	29	40	0
Dairy cattle	6	4	21	0	24	46	0
Poultry	1	2	0	0	44	1	52
Sheep	0	0	0	0	83	0	17
Swine	1	38	1	53	0	7	0
Other animals /a	0	0	0	0	95	0	5

/a Includes deep pit stacks and other.
/b Includes goats, horses, mules, donkeys and camels.

Table 2.10: METHANE EMISSIONS FROM ANIMAL WASTE IN CHINA

Animal	Waste production (kg/d/TAM)	Volatile solids (%)	Emissions potential (m^3/kgVs)	MCE (%)	Animal population (10,000 head) 1988	1990	Methane emissions (Tg/yr) 1988	1990
Cattle	12.5	15	0.10	6.5	10,872.6	11,452.9	0.320	0.337
Dairy cattle	15.6	15	0.14	10.8	222.2	269.1	0.019	0.023
Swine	4.1	10	0.29	10.4	34,220.8	36,240.8	1.023	1.084
Goat	1.6	23	0.13	5.0	9,095.6	9,720.5	0.053	0.056
Sheep	1.8	27	0.13	5.0	11,057.1	11,281.6	0.084	0.086
Poultry	0.1	19	0.26	6.0	1,849.0	1,984.0	0.159	0.170
Horses	18.4	26	0.26	5.0	1,054.0	1,017.4	0.122	0.188
Mules	15.4	20	0.26	5.0	536.6	549.4	0.062	0.064
Donkeys	12.2	20	0.26	5.0	1,105.2	1,119.8	0.085	0.086
Camels	18.4	16	0.21	5.0	47.2	46.3	0.004	0.004
Total	100.1		2.04		70,060.3	73,681.8	1.93	2.03

Note: Emissions estimates are based on the IPPC formula and waste production estimates are derived from IPCC data.

E. ESTIMATING CH_4 AND N_2O EMISSIONS FROM THE BURNING OF AGRICULTURAL CROP RESIDUE

Crop Residue Production

2.16 Residues typically remain after crops are harvested. In addition to straw, the main residue, there are corn cobs, husks, hulls, and remains of the sugar-pressing or oil extraction processes. These residues are combustible substances containing carbon, hydrogen, oxygen, and nitrogen.

2.17 The amount of agricultural crop residue can be estimated from crop production according to the crop/residue ratio. Table 2.11 indicates sown area, yield, and relevant crop residue production from 1987 to 1990. The average annual production of agricultural crop residues from 1987 to 1989 was 0.59 billion tons; in 1990 it reached 0.68 billion tons.

Crop Residue Utilization

2.18 Agricultural crop residue is the primary fuel for cooking and heating in many rural areas. Approximately 60 percent of the annual agricultural crop residues are used as fuel or are burned on the land to prepare for planting the next crop.

Table 2.11: Main Crop Sown Area, Production and Relevant Crop Residue Production Amount in 1987-90

Year	Item	Rice	Wheat	Yam	Corn	Sorghum	Millet	Other grains	Soybean	Cotton	Oilseeds	Hemp	Sugar	Tobacco	Total
	Residue/crop ratio	1	1	1	2	2	1	1	1.5	3	2	1.7	1	1	
1987	Sown area (10,000 ha)	3,219.3	2,879.8	886.8	2,021.2	186.4	268.8	820.1	844.5	484.4	1,118.0	96.7	135.7	112.8	1,4495.7
	Crop production (10,000 tons)	17,441.6	8,776.8	2,822.3	7,982.2	542.8	453.8	1,235.4	1,218.4	424.5	1,527.8	208.4	5,550.4	194.3	4,0473.3
	Crop residue production (10,000 tons)	17,441.6	8,776.8	2,822.3	15,964.4	1,085.6	453.8	1,235.4	1,827.6	1,273.5	3,055.6	354.3	5,550.4	194.3	5,8507.8
1988	Sown area (10,000 ha)	3,198.7	2,874.5	905.4	1,969.2	178.4	251.4	818.8	812.0	553.5	1,061.9	73.5	166.9	155.5	1,4486.9
	Crop production (10,000 tons)	17,122.7	8,573.0	2,722.8	7,999.0	584.7	452.1	1,315.5	1,160.2	414.9	1,320.3	180.9	6,187.5	273.1	3,9930.0
	Crop residue production (10,000 tons)	17,122.7	8,573.0	2,722.8	7,999.0	584.7	452.1	1,315.5	1,160.2	414.9	1,320.3	180.9	6,187.5	273.1	5,9747.2
1889	Sown area (10,000 ha)	3,270.0	2,984.1	909.7	2,035.3	163.0	239.7	815.1	803.4	520.3	1,050.4	56.3	152.9	179.8	1,4655.4
	Crop production (10,000 tons)	18,301.5	9,386.4	2,714.7	8,041.0	450.0	374.7	1,151.1	1,022.8	378.8	1,295.2	112.4	5,803.8	283.0	4,1442.2
	Crop residue production (10,000 tons)	18,301.5	9,386.4	2,714.7	16,082.0	900.0	374.7	1,151.1	1,534.2	1,136.4	2,590.4	191.1	5,803.8	283.0	6,0449.3
1990	Sown area (10,000 ha)	3,306.4	3,075.3	912.1	2,140.1	154.5	227.8	774.3	756.0	558.8	1,090.0	49.5	167.9	159.3	1,4836.2
	Crop production (10,000 tons)	1,9174.8	9,935.6	2,768.1	9,882.3	568.2	456.4	1,288.7	1,110.0	450.8	1,613.2	109.7	7,214.5	262.7	5,4835.0
	Crop residue production (10,000 tons)	1,9174.8	9,935.6	2,768.1	19,764.6	1,136.4	456.4	1,288.7	1,665.0	1,352.4	3,226.4	186.5	7,214.5	262.7	6,8432.1

Source: *Chinese Agricultural Yearbook 1987-90*.

Table 2.12: CH_4 AND N_20 EMISSIONS FROM CROP RESIDUE BURNED

Item	Rice	Wheat	Yam	Corn	Sorghum	Millet	Other	Soybean	Cotton	Oilseeds	Hemp	Sugar	Tobacco	Total
					— Annual Average in 1987-89 —									
P crop production (10,000 ton)	1,7621.9	8,912.1	2,753.3	8,007.4	525.8	426.9	1234.0	1133.8	406.1	1381.1	193.5	5,847.2	250.1	
R residue/crop ratio	1	1	1	2	2	1	1	1.5	3	2	1.7	1	1	
B residue burned (%)	60	60	60	60	60	60	60	60	60	60	60	60	60	
DM dry material content (%)	83	83	45	40	40	83	62	45	50	45	80	15	50	
C C content (%)	51.44	48.53	42.26	47.09	47.09	41.44	44.64	45.00	45.00	45.00	45.00	45.00	45.00	
C total carbon amount burned (1,000 t)	3,636.7	2,153.9	314.2	1809.9	118.8	88.1	204.9	206.6	164.5	335.6	71.1	236.8	33.8	9,374.9
CH_4- C(low) 10,000 ton	22.9	13.6	1.98	11.4	0.75	0.56	1.29	1.30	1.04	2.11	0.45	1.49	0.21	59.1
CH_4-C(high) 10,000 ton	42.5	25.2	3.68	21.2	1.39	1.03	2.40	2.42	1.92	3.93	0.83	2.77	0.40	109.7
CH_4 emission (low) (10^4t)	30.5	18.1	2.64	15.2	1.00	0.74	1.72	1.74	1.38	2.82	0.60	1.99	0.26	78.7
CH_4 emission (high) (10^4t)	56.7	33.6	4.90	28.2	1.85	1.37	3.20	3.22	2.57	5.23	1.11	3.69	0.53	146.2
N_20-N(low) 10,000 ton)	0.18	0.1	0.016	0.090	0.0059	0.0044	0.010	0.010	0.0082	0.017	0.0036	0.012	0.0017	0.047
N_20-N(high) (10,000 ton)	0.65	0.39	0.057	0.33	0.021	0.016	0.037	0.037	0.030	0.06	0.013	0.043	0.0061	1.69
N_20 emission (low) (10^4t)	0.29	0.17	0.025	0.14	0.0093	0.0069	0.016	0.016	0.013	0.026	0.0056	0.019	0.0027	0.74
N_20 emission (high) (10^4t)	1.02	0.061	0.089	0.51	0.034	0.025	0.058	0.058	0.047	0.095	0.020	0.067	0.0096	2.65
					— 1990 —									
P crop production (10,000 ton)	19174.8	9935.6	2768.1	9882.3	568.2	456.4	1288.7	1110.0	450.8	1631.2	109.7	7214.5	262.7	
R residue/crop ratio	1	1	1	2	2	1	1	1.5	3	2	1.7	1	1	
R residue burned (%)	60	60	60	60	60	60	60	60	60	60	60	60	60	
DM dry material content (%)	83	83	45	40	40	83	62	45	50	45	80	15	50	
C C content (%)	41.44	48.53	42.26	47.09	47.09	41.44	44.64	45	45	45	45	45	45	
C Total carbon amount burned (10,000 ton)	3,957.1	2,401.2	315.8	2,233.7	128.4	94.2	214	202.3	182.6	392.0	40.3	292.2	35.5	10,489.3
CH_4-C(low) (10^4t)	24.9	15.1	1.99	14.1	0.81	0.59	1.35	1.27	1.15	2.47	0.25	1.84	0.22	66.08
CH_4-C (high) (10^4t)	46.3	28.1	3.70	26.1	1.50	1.10	2.50	2.37	2.14	4.59	0.47	3.42	0.41	122.7
CH_4 emission (low) (10^4t)	33.2	20.2	2.65	18.8	1.08	0.79	1.80	1.70	1.53	3.29	0.34	2.45	0.30	88.1
CH_4 emission (high)	61.7	37.4	4.93	34.8	2.00	1.47	3.34	3.16	2.85	6.11	0.63	4.58	0.55	163.6
N_20-N(low) (10,000 ton)	0.20	0.12	0.016	0.11	0.0064	0.004	0.011	0.010	0.0091	0.020	0.0020	0.015	0.0018	0.52
N_20-N(high) (10,000 ton)	0.71	0.43	0.057	0.4	0.023	0.0177	0.039	0.036	0.033	0.071	0.0073	0.053	0.0064	1.89
N_20 emission (low) (10^4t)	0.31	0.19	0.025	0.18	0.010	0.0074	0.017	0.016	0.014	0.031	0.0032	0.023	0.0028	0.82
N_20 emission (high) (10^4t)	1.12	0.68	0.089	0.63	0.036	0.027	0.061	0.057	0.052	0.11	0.011	0.083	0.010	2.97

Emissions estimates are based on IPCC formula.

CH_4 and N_2O Emissions from the Burning of Agricultural Crop Residue

2.19 Agricultural crop residues are classified and the carbon content of each is calculated; the total carbon burned is calculated from this. The following equation is adopted:

$$\text{Total carbon burned (ton C)} = \Sigma(P_c \times R_c \times B_c \times DM_c \times C_c)$$

where:

P= Crop production (ten thousand tons)
R= Residue/crop ratio
B= Residue burned (percent)
DM= Dry material content (percent)
C= Carbon content (tons C/ton DM)
c= Crop type

CH_4 Emission

CH_4-C emission (low)= total carbon burned x 0.9 x 0.007
CH_4-C emission (high)= total carbon burned x 0.9 x 0.013
CH_4 emission (low, high)= CH_4-C emission (low, high) x 16/12

N_2O Emission

N_2O-N emission (low)= total carbon burned x 0.01 x 0.005
N_2O-N emission (high)= total carbon burned x 0.02 x 0.009
N_2O emission (low, high)= CH_4-N emission (low, high) x 44/28

3. RESEARCH AIMED AT REDUCING GHG EMISSIONS FROM AGRICULTURAL SOURCES

A. SEMIDRY RICE CULTIVATION

3.1 Semidry rice cultivation uses ridge farming; i.e., creating furrows in the field, transplanting seedlings on a ridge side, and flooding the furrows two-thirds full. This method can improve soil structure; balance the relationship of water, heat, air, and fertility of soil; encourage the decomposition of organic substances and transformation of soil nutrients; mitigate the harmful effects of cold and toxins; speed rice growth; and increase yields. The semidry rice cultivation technique yields about 1,120 kg per hectare more at harvest and as much as 1,500-2,250 kg per hectare more depending on the soil, fertilizer application, temperature, and irrigation conditions. In 1982, the Ministry of Agriculture's Extension Service and the Sichuan Provincial Agricultural Department launched a pilot program at selected sites in Sichuan Province which later spread throughout the province. It was subsequently introduced in the southern provinces, where it was widely adopted between 1985 and 1988. Semidry cultivation of rice has come into use on 674,000 ha of land; it was adopted on 344,500 ha in 1988 alone. In Sichuan, Fujian, and Guangdong, 60.8 percent of the areas fit for the technique now use it.4/ At present, the technique is being combined with fish farming, azola cultivation, and interplanting of aquatic vegetables and medicinal plants to further raise rural incomes.5/

3.2 Semidry rice culture not only enhances the overall productivity of paddy fields, but can also help reduce CH_4 emissions. The Nanjing Institute of Environmental Protection has studied the method for three years and found that, compared with conventional cultivation, semidry rice culture could reduce the level of CH_4 emissions from paddy fields by 31-43 percent 6/ without compromising output. However, because it demands intensive soil preparation and water management and is not suited to all terrains and growing conditions, its use in China may be limited. Implementation is expected to reach 15-25 percent by the year 2020.

4/ *China Agricultural Yearbook*, 1987 and 1990.

5/ Comprehensive utilization of paddy field has been adopted on 400,000 ha in four years, yielding 510 million kg grain and Y 440 million income.

6/ Li Debo et al., 1993.

B. Intermittent Irrigation of Paddy Fields

3.3 Although rice is grown in flooded fields, rice shoots do not have to be submerged at all times. During certain periods of growth, it is necessary only to keep the soil moist, while in other periods the fields can even become dry, thus ventilating the soil. Appropriate timing of irrigation can increase rice productivity.

3.4 Methane emissions from paddy fields occur when organic substances mineralize as a result of microorganisms metabolizing under anaerobic conditions. Research has shown that by reducing the time during which fields are flooded and by thus making it impossible for methanogens to survive in the soil, CH_4 emissions will be suppressed. Research by Wu Haibao et al. (1993) shows that while the average flux of CH_4 emissions from flood-irrigated fields is 6.4 mg/m^2.h, it is one-third the amount—2.2 mg/m^2—from nonflood irrigated ones. Research by Cheng Zhongliang et al. (1993) and Shao Kesheng (1993) further supported this finding (Table 3.1). Intermittent irrigation reduced the flux of CH_4 emission by 12-59 percent over conventional flooding irrigation and did not reduce rice output.

Table 3.1: Flooding vs. Intermittent Irrigation: Comparison of Emissions Flux
(10,000 tons)

	Average flux (CH_4mg/m^2.h)			Output (kg/ha)	
Year	Flooding irrigation	Intermittent irrigation	Ratio of reduction	Flooding irrigation	Intermittent irrigation
1990	35.9	14.6	59	5,220	5,445
1991	20.4	18.0	12	n/a	n/a
1992	23.9	20.7	13	5,040	5,190
1991	10.0	8.7	13	4,395	4,545
1992	8.5	5.6	34	5,970	5,865

Sources: Chen Zongliang et al. 1993. Research on the effect of different cultivation methods on methane emission from rice paddies. *Rural Eco-Environment (China) 1993 Supplement*, pp. 43-47; Shao Kesheng. Preliminary study on the relationship of agricultural management measures and methane emission flux from rice paddy near Beijing. *Rural Eco-Environment (China) 1993 Supplement*, pp. 19-22.

3.5 Irrigation that alternates heavy and light flooding and allows dry periods has become common in the high-yield rice growing areas of China. For instance, in the rice growing areas of the south, shallow water irrigation dominates the tillering stage; irrigation may then be stopped to desiccate the fields and stimulate root growth. At the intermediate stage, fields are allowed to dry several times. From the boot to earing stages, the fields are again flooded shallowly and often to ensure that water from previous flooding does not mix with the new water, and to keep the water clear and the soil hard. In the milking stage, shallow water irrigation is alternated with periods of desiccation until the crop matures. The fields are also allowed to dry at the jointing stage and are in turn irrigated deeply and shallowly in the middle of the milking stage. Water layers are deeper and fields are watered longer in the north than in the south because evaporation is quicker, the temperature colder, and leakage greater.

3.6 Despite the widespread adoption of this technique, there are obstacles to its more extensive application. Some regions are short of water and cannot irrigate the fields as needed; other areas are low lying and slow in draining water, thus cannot dry the field as necessary. It is estimated that by the year 2020, the technique will be applied in 10-15 percent of rice production.

C. Breed Improvement of Cattle

3.7 In China, methane emissions from ruminants such as cattle and sheep account for 88 percent of total livestock emissions (Table 2.8). Cattle alone account for 72.6 percent (Table 3.2). It is likely that breed improvement will enhance the productivity of individual cattle, reduce the number of head needed to satisfy the demand for livestock products, and reduce the amount of CH_4 emission per unit of animal product.

Table 3.2: Classification of Cattle and CH_4 Emissions (1988)

Total livestock ('000)	Total cattle		Yellow cattle		Buffalo		Yak		Pedigree & dairy cattle	
	('000)	(%)	('000)	(%)	('000)	(%)	('000)	(%)	('000)	(%)
Population	110,948	(100)	74,659	(67.4)	21,067	(20)	13,000	(11.7)	2,222	(2)
CH_4 emissions (Tg)	4.58	(72.6)	2.94	(46.6)	1.11	(17.6)	0.41	(6.5)	0.12	(1.9)

Technical Feasibility

3.8 In 1978, the State Scientific and Technological Commission decided that artificial insemination (AI) should be adopted to introduce improved foreign and domestic breeds through crossbreeding. The program was initially introduced in 114 counties of 26 provinces and autonomous regions. Breed improvement of cattle was listed as a key task in both the Sixth and Seventh Five-Year Plans. To aid in accomplishing this task, preferential loans were issued from 1981 to 1988 by the International Fund for Agricultural Development.

3.9 In 1980, 140 bulls were imported from North America and Western Europe. In 1981, the technique of frozen semen artificial insemination (FSAI) was introduced, and frozen semen from Simmental bulls began to be used for crossbreeding. Currently, there are 919 head of parent bulls involved in the program.

Table 3.3: EXTENSION OF BREED IMPROVEMENT IN CHINA (1978-88)

Year	Number of counties involved	Improved breed	Percent of population	Conception rate
1978	114	404,000	5.5	77.9
1988	977	7,521,000	13.9	81.6

3.10 Between 1978 and 1988, the number of counties participating in the improvement project grew from 114 to 977, 51 percent of the nation's total. The proportion of improved cattle nationwide grew from 5.64 percent to 13.9 percent and the conception rate using AI increased as well (Table 3.3). By 1988, there were 6,829 improvement stations throughout the country, 899,000 trained technical personnel, and 39 bull stations. The bull stations are responsible for producing frozen semen and liquid nitrogen, organizing demonstrations, and training technical personnel. Annually, these stations produce 10.7 million units of granulated frozen semen which is used to impregnate 3.617 million breeding cows.

Economic Feasibility

3.11 Improving indigenous cattle using AI crossbreeding has several benefits. It takes full advantage of improved parent bulls (on average a bull can provide semen for 3,000 to 5,000 cows, which is 100 times what is possible with natural service); increases the number of improved herds, and decreases the number of parent bulls needed, thereby reducing feed outlay. In addition, AI can enhance the productivity of the crossbred offspring. Crossbreeds gain weight more quickly than domestic yellow cattle and have a higher feed conversion ratio. In the 1980s, the average cow produced less than 80 kg of meat (without milk); however, a Simmental crossbreed can produce either 200 kg of meat or 2,000 kg of milk, and a crossbred buffalo can produce 1500 kg of milk, (an indigenous buffalo produces about 600 kg of milk). It is anticipated that by the year 2000, there will be 23 million head of buffalo, including one million crossbreeds. A crossbred yak produces an average of 750 kg of milk, up to three times more than an indigenous yak. The amount of meat produced by a crossbred yak doubles.

3.12 In addition to allowing producers to select breeds, artificial insemination avoids many of the shortcomings of natural service. For example, AI can prevent premature mating, permit a fixed breeding date, and increase the conception rate.

3.13 The use of frozen semen produces better results than the use of fresh semen. Moreover, frozen semen artificial insemination (FSAI) is easily mastered. With a training period of about 15 days a veterinarian can master the skill and produce a conception rate of 50 to 80 percent. The FSAI program has become more efficient with time. For example, the use of liquid nitrogen, which is used to freeze semen, has declined from an initial 0.47 cubic liters per head to 0.19 cubic liters per head. Also, semen cell consumption has declined from 3.8 cells per head to 2.5 cells per head.

3.14 From a commercial beef producer's point of view, the FSAI program has been a success. In the case studies presented in Appendix A, producing crossbreeds instead of local cattle yielded a financial rate of return exceeding 75 percent.

Evaluation of Potential for Reducing CH_4 Emissions

3.15 Improving cattle through FSAI crossbreeding can increase the usable carcass weight, increase the fertility rate, reduce the number of bulls needed, and increase individual productivity. All of these help to reduce CH_4 emissions per kilogram of product. There is the potential to reduce methane emissions by almost 11 percent per animal. With the cattle population predicted to increase from 100 million in 1988-90 to almost 169 million by 2010, the impact on methane emissions could be substantial.

D. Use of Ammoniated Straw

3.16 China's agricultural sector produces as a by-product vast quantities of straw. Some of this straw is fed to cattle, but much of it goes to waste. For example, a common practice is to burn the straw in the field to clear the area for a new crop. This occurs even though cattle feed is limited. The primary reasons for this paradox are that cattle have difficulty digesting raw straw and that the feed source has a low nutrient value. These problems, coupled with a shortage of high-quality feed, have hindered the development of China's cattle industry.

3.17 In the early 1980s, China started a pilot program of using ammoniated straw to feed cattle. While the program is only now being adopted by producers, it has caught on quickly. There are several reasons for this. First, investment costs are low relative to the costs of cattle production. Second, the technique of ammoniating feed is easy to understand and implement. Finally, and perhaps most importantly, the financial returns to ammoniating straw are very high (for details, see the case study in Appendix B). A total of 43,000 tons of straw were ammoniated in 1986, while in 1991 the number grew to 3.71 million tons, an 86-fold increase.7/ The proportion of cattle fed ammoniated straw has risen from 0.2 percent in 1986 to approximately 2.0 percent in 1991.

3.18 The method is suitable for widespread implementation in the vast farming areas north of the Changjiang River. Straw and stalks are ammoniated by cutting them to

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7/ *Fodder* (China) 1992, no. 8.

2-3 cm lengths and mixing them with urea and water. The mixture is placed in an ammoniation tank, stirred, pressed, covered with a plastic film, and allowed to ferment. Recommended ratios of urea, water, and straw vary. For 100 kg of straw, between 3-5 kg of urea and 35-80 kg of water are recommended. The recommended duration of fermentation varies from two to four weeks.

3.19 Ammoniated straw contains two to three times as much crude protein as its raw counterpart, and the amount and speed of consumption and digestion increase by 20 percent. Nutritionally, 1 kg of ammoniated straw is equivalent to 0.4-0.5 feed units of oats. Owing to increases in the amount consumed and the improved nutritional content, cattle tend to grow faster and gain more weight. With use of ammoniated straw, feeding time can be shortened by 2.5-3.0 years, to 1.5-2.0 years.

3.20 Research at the Hebei Animal Husbandry Research Institute found that daily weight gains averaged 644 grams when treated straw was used versus 348 when untreated straw was used—an 85 percent improvement.8/ This gain, coupled with low investment and straw treatment costs, resulted in a financial rate of return of 110 percent in the case study presented in Appendix B. Sensitivity analysis indicates that this high return is very stable to changes in the factors affecting the analysis.

3.21 At present, most of the cattle industry in China still uses crude feeding and management practices. The result is low productivity and relatively high methane emissions per unit of product (e.g., per kg of meat or milk). Thus, improvements that not only enhance the economic viability of the industry but also reduce CH_4 emissions per unit of product are socially desirable. With the use of ammoniated feed, daily methane emissions increase to 6.27 kg from 5.5 kg without treatment, but on a per-kilogram weight gain basis emissions fall from .52 kg to .32 kg, a 38.5 percent decline (Leng, 1991). This technique shows great promise for China's beef industry, which continues to expand rapidly. Based on the current rate of development, it is likely that approximately 20 percent of the feed used in cattle production will be ammoniated by the year 2020.

E. FERTILIZERS

3.22 Fertilizers are classified into two broad categories—organic and inorganic. Organic fertilizers include plant and animal waste. The principal plant waste is crop straw, but other sources include husks, hulls, stalks, corn cobs, and other processing by-products. Animal waste includes dung, urine, and animal processing by-products. Greenhouse emissions from straw and dung are emphasized in this section, but much of what is presented also applies to the other forms of organic material.

8/ Both treatments included 1.5 kg of cottonseed cake and a mineral supplement. As reported by Dolberg, "Cottonseed cake supplementation dramatically improves feed efficiency, bringing feed dry matter requirements down from 20 kg or more per kg live weight gain to an interval of 10 to 12 kg for 1 to 2 kg." Going from 0 to 1 kg cottonseed supplementation results in weight gains that are more than double (Dolberg, 1992). It is important to note that with 1-2 kg cottonseed supplementation, straw still constitutes 75 percent of the diet.

3.23 Decomposition of organic material in an anaerobic environment results in methane production. Such an environment exists in flooded rice fields. Sources of organic material include rice straw, root exudates and root material, and other biomass.

3.24 An anaerobic environment can also be created by way of animal waste disposal. The potential methane production from animal waste is high, but typically only 10 percent of this potential is realized. The waste disposal method used determines the level of methane production. The IPCC cites the following disposal methods and their methane-generating potential:

Disposal method	Methane generating potential
Pasture	low
Liquid/slurry storage	high
Solid storage	similar to leaving in the pasture (low)
Anaerobic lagoon	high (often methane is recovered)
Drylot	low
Daily spread	very low

3.25 The use of animal waste on flooded rice paddies is similar to the liquid/slurry storage method, which has a relatively high methane generating potential. On the other hand, research sponsored by NEPA and the U.S. EPA, and conducted by the Chinese Academy of Sciences' Institute for Atmospheric Physics and Peking University found that flux resulting from manure applications can be cut by 40 to 60 percent by aerobic composting of green manure before application.

3.26 Anaerobic digestion is also used to reduce methane emissions from organic fertilizers on flooded rice paddies. The Chinese Ministry of Agriculture's Agro-Environmental Protection Institute conducted research on the effects of biogas residue manuring on the methane emissions of paddy fields. Findings of experimental fertilizer trials indicate that, on average, emissions flux from biogas residue is 30 percent less than what it would have been with untreated organic fertilizers and 21 percent less than with chemical fertilizer treatment (Tao Zhan et al., 1993).

3.27 The use of inorganic fertilizers such as ammonium sulfate or urea may help decrease methane emissions in flooded rice paddies by as much as 40 percent when compared with organic manure fertilization. Methane reduction is highest when fertilizer is worked deeply into the soil.

3.28 The primary greenhouse gas emission potential of inorganic, nitrogen-based fertilizers, however, is in the form of N_2O. Nitrous oxide is produced naturally in the soil by nitrification and denitrification. Nitrogen fertilizer applications can increase these emissions since some of the applied fixed nitrogen is converted to N_2O and released into the atmosphere. Factors that affect the rate of N_2O emissions include soil temperature, precipitation, type of fertilizer (Table 2.5), mode of application, and soil conditions. The type of fertilizer and mode of application are clearly management decisions. The IPCC describes the following management practices that affect N_2O levels:

(a) **Application Rates.** The relationship between the rate of fertilizer application and N_2O emissions is positive but probably nonlinear.

(b) **Timing.** Fall applications result in higher emissions than like applications in the spring.

(c) **Sowing.** Deep placement appears to reduce N_2O emissions when compared with broadcasting.

(d) **Cultivation.** Tilling tends to result in lower emissions than nontilling.

Section 4 includes prediction of N_2O emissions resulting from inorganic fertilizer use to the year 2020. The expected rapid growth in China's fertilizer use underscores the importance of these predictions.

F. RURAL ENERGY

Rural Energy Resources and Consumption

3.29 Energy for development and use in rural neighborhoods comes mainly from biological sources, small hydropower stations, small coal mines, and solar- and wind-powered generators. In 1990, rural areas consumed 583 million tons of standard coal equivalent—nearly half of China's total energy consumption. Of this total, 50.6 percent came from biological energy sources. Of the remainder, coal accounted for 34.8 percent; electricity 8.6 percent; oil 5.9 percent; and gas 0.1 percent.

3.30 Of the total energy consumed by rural areas in 1990, almost half—288 million tons—went for commercial use. Noncommercial energy consumption was 295 million tons, or 50.6 percent of the whole.9/

Changes in Structure of Rural Energy Consumption

3.31 In recent years, the structure of rural energy consumption has changed considerably. The proportion of energy used for commercial purposes has increased. In 1990, rural energy consumption was 2.5 times that in 1980. Coal consumption grew 277 percent, electricity 125 percent, and oil 57 percent during that period. However, noncommercial energy consumption grew by only 16 percent. Thus, the proportion of energy consumed by noncommercial users has been shrinking.

9/ *Rural Energy Development and Demand Technology*, Ministry of Agriculture, ed. 1992.

3.32 Because of these changes, conflicts have emerged between the supply and demand of rural energy. At present, 900 million farmers do not have enough energy for daily use. Their share of energy resources per capita is only half the world average. Meanwhile, wealthier farmers are more willing to pay for high-grade energy, such as coal, methane, solar, or wind sources. In 1992, there were 21.19 million farmers' households using high-quality fuel, and the demand is increasing by more than 30 percent annually.10/

3.33 It is predicted that in 1995, rural energy consumption will reach 611 million tons of standard coal equivalent, an increase of 12.6 percent and 4.8 percent over consumption targets in the Sixth and Seventh Five-Year Plans respectively.11/ Table 3.4 provides figures for rural energy consumption and expected demand.

Table 3.4: RURAL ENERGY CONSUMPTION (10,000 tons standard coal equivalent)

	Total	Commercial energy	Bio-energy
1985			
Total quantity	51,756 (100.0)	20,271 (39.2)	31,485 (60.8)
Production quantity	15,085 (29.1)	13,771 (91.3)	1,314 (8.3)
Daily use quantity	36,671 (70.9)	6,500 (17.7)	30,171 (82.3)
1990			
Total quantity	58,288 (100.0)	28,776 (49.4)	29,512 (50.6)
Production quantity	22,648 (38.9)	21,505 (95.0)	1,143 (5.0)
Daily use quantity	35,640 (61.1)	7,271 (20.4)	28,369 (79.6)
1995			
Total quantity	61,085 (100.0)	34,660 (56.7)	26,425 (43.3)
Production quantity	27,546 (45.1)	26,689 (96.9)	857 (3.1)
Daily use quantity	33,539 (54.9)	7,971 (23.8)	25,568 (76.2)

Source: *Rural Energy Development and Demand Tendency*, 1992, Ministry of Agriculture, ed.

3.34 Table 3.4 shows that commercial energy consumption is accounting for a larger portion of general energy consumption each year—from 39.7 percent in 1985 to a projected 56.7 percent in 1995. In contrast, the proportion of biological energy

10/ *Fodder* (China) 1992, no. 8.

11/ *Rural Energy Development and Demand Tendency*. Ministry of Agriculture, ed., 1992.

consumption decreases each year—from 60.8 percent in 1985 to a projected 43.3 percent in 1995.

3.35 In recent years, China's rural areas have benefited from access to new sources of energy. By the end of 1990, 120 million households were using wood- and coal-saving stoves; 25 million were using wood- and coal-saving kangs; 5 million were using family-sized biogas generating ponds; and 1 million square meters of solar water heaters and 120,000 solar cookers were in use. In 1995, it is estimated that 160 million households will use wood- and coal-saving stoves; 40 million will use wood- and coal-saving kangs; and solar water heaters will increase by 2 million square meters and solar cookers by 150,000. Compared with 1990, there will be an increase of 6.7 percent, 12 percent, 4 percent, 20 percent, and 5 percent respectively. As a result, nearly 60 million tons of biological fuel can be saved, equal to 10 percent of the total quantity of straw in China.

3.36 Based on the above analysis, commercial energy and the use of new energy resources will increase while the amount of biological energy burned in traditional ways will decline by an estimated 10-20 percent by the year 2020.

4. PREDICTION OF CH_4 AND N_2O EMISSIONS FROM AGRICULTURAL SOURCES

A. Prediction of Methane Emissions from Paddy Fields

4.1 Paddy fields are the major agricultural source of CH_4 emissions. At present, the volume of global methane emissions from paddy fields is reported to be about 60 Tg/yr. The volume of methane emissions from paddy fields in China in 1990 was estimated at 14.4 Tg, close to 25 percent of the world total.

4.2 A differential equation model was used to predict future crop area/output and nitrogen fertilizer use based on existing statistics. A nonhomogenous first order equation of the first degree was utilized, with a general form as follows:

$$\frac{dx}{dt}+ax=u(mu)$$

where

a, u = numerical constants
x = area, output, or fertilizer use
t= time (year)

The general solution for this equation, given an initial condition at time t=1,x(t), is stated as follows:

$$x = Ae^{-at} + u/a \text{ where}$$
$$A = x(0) - u/a = \text{constant.}$$

The values for a, u, and A for early, single crop, and late rice are provided in Appendix C.

4.3 Table 4.1 shows predictions for the area of rice sown. The proportion of various kinds of rice to the total paddy seeded area is shown in Table 4.2.

4.4 Based on the predictions in Tables 4.1 and 4.2, the volume of methane emissions from paddy fields has been predicted for the years 2000, 2010, and 2020 for each of three scenarios: high, medium, and low.

(a) **High Scenario**. With population growth and improvement of living standards, the average emissions from paddy fields are increasing and will continue to increase unless effective technologies and measures are taken.

Table 4.1: PREDICTION OF AREA SOWN WITH EARLY, SINGLE CROP, AND LATE RICE IN CHINA
(thousand ha)

Rice	1990	2000	2010	2020
Early	9,418	8,779	8,317	7,880
Single	13,808	15,940	18,549	21,584
Late	9,839	9,602	9,493	9,386
Total	33,065	34,321	36,359	38,850

Table 4.2: PREDICTED PROPORTION OF AREA SOWN WITH EARLY, SINGLE CROP, AND LATE RICE IN CHINA
(%)

Type	1990	2000	2010	2020
Early	28.48	25.58	22.88	20.28
Single	41.76	46.44	51.02	55.56
Late	29.76	27.98	25.11	24.16

(b) **Medium Scenario.** There are two primary means for controlling methane emissions from paddy fields in China today: semidry cultivation and intermittent irrigation. Research conducted in China shows that semidry cultivation could decrease the methane emission flux by 31-43 percent per hectare compared with flooded cultivated paddy fields. Intermittent irrigation could reduce methane emissions flux by 12-59 percent. It is predicted that 10 percent of China's paddy field area will use the intermittent irrigation technique by the year 2020, while up to 15 percent of the fields seeded that year will use the semidry cultivation method.

(c) **Low Scenario.** If there are favorable policies toward the control of methane emissions from paddy fields in China and the techniques for controlling these emissions are widely adopted, the area employing intermittent irrigation could reach 15 percent by the year 2020 and the area cultivated with the semidry cropping method could reach 25 percent.

4.5 Tables 4.3, 4.4, and 4.5 depict the high, medium, and low scenarios for paddy field methane emissions over the next 30 years.

Table 4.3: PREDICTION OF PADDY FIELD METHANE EMISSION OF VARIOUS RICE: HIGH SCENARIO (Tg/yr)

	1990		2000		2010		2020	
Type	Median	Range	Median	Range	Median	Range	Median	Range
Early	3.60	1.40-5.80	3.39	1.33-5.45	3.22	1.26-5.17	3.05	1.20-4.89
Single	6.55	2.60-10.50	7.56	3.03-12.10	8.80	3.52-14.08	10.24	4.10-16.38
Late	4.25	1.70-6.80	4.14	1.65-6.64	4.09	1.62-6.55	4.04	1.61-6.48
Total	14.40	5.70-23.10	15.10	6.01-24.19	16.10	6.41-25.79	17.33	6.90-27.75

Table 4.4: PREDICTION OF PADDY FIELD METHANE EMISSION OF VARIOUS RICE: MEDIUM SCENARIO (Tg/yr)

	1990		2000		2010		2020	
Type	Median	Range	Median	Range	Median	Range	Median	Range
Early	3.60	1.40-5.80	3.25	1.25-5.25	2.94	1.10-4.78	2.64	0.96-4.32
Single	6.55	2.60-10.50	7.24	2.83-11.65	8.05	3.07-13.02	8.86	3.28-14.45
Late	4.25	1.70-6.80	3.96	1.54-6.39	3.74	1.41-6.06	3.50	1.28-5.71
Total	14.40	5.70-23.10	14.45	5.62-23.28	14.72	5.58-23.86	15.00	5.51-24.48

Table 4.5: PREDICTION OF PADDY FIELD METHANE EMISSION OF VARIOUS RICE: LOW SCENARIO (Tg/yr)

	1990		2000		2010		2020	
Type	Median	Range	Median	Range	Median	Range	Median	Range
Early	3.60	1.40-5.80	3.16	1.19-5.12	2.77	1.00-4.53	2.39	0.18-3.98
Single	6.55	2.60-10.50	7.04	2.71-11.36	7.57	2.78-12.36	8.04	2.77-13.32
Late	4.25	1.70-6.80	3.85	1.47-6.23	3.52	1.28-5.75	3.17	1.08-5.26
Total	14.40	5.70-23.10	14.04	5.38-22.71	13.85	5.07-22.64	13.61	4.67-22.56

4.6 The high scenario predicts that by 2020 the total methane emission volume of paddy fields will be 17.33 Tg/yr (median), a net increase of 2.93 Tg from 1990. The medium scenario predicts that the total volume of methane emissions from paddy fields will be 15.00 Tg/yr (median), a net increase of 0.6 Tg over 1990. The low scenario predicts that the total methane emission volume from paddy fields will be 13.61 Tg/yr (median) by the year 2020, a net decrease of 0.79 Tg. The high scenario shows a marked increase of 20.34 percent in 2020 compared with 1990. The medium scenario shows a slight increase of 4.17 percent in 2020 compared with 1990. The low scenario shows a slight decrease of 5.48 percent in 2020 compared with 1990. By the year 2020, the low scenario will show a 3.72 Tg/yr decrease in CH_4 emission compared with the high scenario. The implementation of different measures for reducing methane emissions will clearly affect paddy field methane emissions.

4.7 Based on the studies and predictions, it can be concluded that methane emissions from paddy fields can be effectively controlled in China as long as there are comparatively sound technical and economic policies. Application of the predicted medium scenario, i.e., keeping the CH_4 emissions at an even or slightly increasing level, is practical.

B. Prediction of Emissions from Nitrogen Fertilizers

4.8 Nitrogen fertilizer is an important agricultural source of N_2O emissions. In recent years, the use of aqua ammonia has decreased while the use of other kinds of nitrogen fertilizers has increased rapidly. However, the use of nitrogen per unit area remains low compared with industrialized countries. In coming decades, China will increase the production and use of chemical fertilizers to ensure stable and high-yielding agriculture. At the same time, the effective utilization rate of fertilizers—just over 30 percent compared to 60 percent in developed countries—is also expected to increase rapidly.

4.9 The changes in the amount of chemical fertilizers applied in recent years are shown in Table 4.6.

Table 4.6: Application of Ammonia Water and Nitrogen, 1985-91
(pure nitrogen, thousand tons)

Type	1985	1986	1987	1988	1989	1990	1991
Ammonia water	201	189	240	176	174	118	95
Nitrogen	12,050	13,126	13,028	13,995	15,187	16,259	17,261

Source: *China Agricultural Yearbook 1986-92.*

4.10 The differential equation growth model (Appendix C) has been used to predict the amount of ammonia water and other nitrogen fertilizers that will be used in the next 30 years (Table 4.7). Predictions have also been made for the N_2O emissions that will result from application of these fertilizers. The prediction includes three scenarios: high, medium, and low (Table 4.8).

Table 4.7: PREDICTED APPLICATION OF AMMONIA WATER AND NITROGEN IN CHINA (pure ammonia, thousand tons)

Type	1990	2000	2010	2020
Ammonia water	118	49.7	17.2	6.0
Nitrogen	16,259	29,235	53,173	96,712

Table 4.8: PREDICTED N_2O EMISSIONS VOLUME RESULTING FROM APPLICATION OF NITROGEN (thousand tons)

		High scenario		Medium scenario		Low scenario	
Year	Type	Median	Range	Median	Range	Median	Range
1990	Ammonia	2.34	1.25-9.82	2.34	1.25-9.82	2.34	1.25-9.82
	Nitrogen	17.68	0.16-1,099.43	17.68	0.16-1,099.43	17.68	0.16-1,099.43
	Total	20.02	1.41-1,109.25	20.02	1.41-1,109.25	20.02	1.41-1,109.25
2000	Ammonia	0.81	0.43-3.40	0.75	0.40-3.14	0.62	0.33-2.62
	Nitrogen	32.16	0.29-1,999.67	29.68	0.27-1,845.85	24.74	0.23-1,538.21
	Total	32.97	0.72-2,003.07	30.43	0.67-1,848.99	25.36	0.56-1,540.83
2010	Ammonia	0.28	0.15-1.18	0.24	0.13-1.00	0.2	0.10-0.82
	Nitrogen	58.49	0.53-3,637.01	49.49	0.45-3,077.47	40.49	0.37-2,517.93
	Total	58.77	0.68-3,638.19	49.73	0.58-3,078.47	40.69	0.47-2,518.75
2020	Ammonia	0.10	0.05-0.41	0.08	0.04-0.31	0.06	0.03-0.25
	Nitrogen	106.38	0.97-6,615.07	81.83	0.74-5,088.51	65.47	0.60-4,070.81
	Total	106.48	1.02-6,615.48	81.91	0.78-5,088.82	65.53	0.63-4,071.06

Note: The median value in the table does not state the value of range data. It is calculated according to data supplied by Elchner in *OECD/OCED Estimation of Gas Emissions and Sinks Final Report* from OECD (pp. 5-50). Experts Meeting, 18-21 February 1991. The range coefficient is based on IPCC data.

(a) **High Scenario.** The use of nitrogen per unit area lags behind industrialized countries. To further increase per hectare grain production and meet the needs of an increasing population, there will be a rapid increase in per unit area application of chemical fertilizers (Table 4.7). At the same time, if the utilization rate of chemical fertilizers is not increased from its current rate of 35 percent, emissions from nitrogen fertilizers will rise dramatically.

(b) **Medium Scenario.** The *2020 Strategic Targets Research for Environmental Protection* issued by the CMA's Environmental Protection Monitoring Center, state that by 2020 the utilization rate of nitrogen fertilizer in China will have increased from about 35 percent to 50-60 percent. The medium scenario is based on an assumed 50 percent effective utilization rate for nitrogen.

(c) **Low Scenario.** In its Mid- and Long-Term Development Outline for Agro-Science and Technology, the Ministry of Agriculture states that the effective utilization rate of chemical fertilizers is to reach 60 percent. The low scenario is based on an assumed 60 percent effective utilization rate for nitrogen fertilizer.

4.11 The high scenario predicts N_2O emissions in the year 2020 to be 5.32 times the level of 1990; the medium scenario predicts it will increase 4.09 times; and the low scenario, 3.27 times. If there are no significant breakthroughs in the techniques for controlling N_2O emissions while applying nitrogen fertilizers, increased emissions will be inevitable.

C. Prediction of Methane Emissions from Livestock

4.12 China's livestock includes cattle (cattle, buffalo, cows, and yaks), camels, horses, mules, donkeys, pigs, and goats. The changes in livestock numbers in recent years are shown in Table 4.9.

4.13 Among livestock in China, the major sources of methane emissions are cattle, buffalo, cows, and yaks, which account for 73 percent of the total (Table 4.10). Emissions from cattle alone account for 64 percent of this subtotal. Therefore, the predicted emission volume is related only to that of cattle. Cattle data from the authors' case analysis are used at the predicted coefficient. Meanwhile, most of the cattle in China are raised for meat, milk, and draft labor. By studying the demands for meat supplies, cattle methane emissions during various periods can be predicted.

Table 4.9: CHANGES IN LIVESTOCK POPULATION (10,000 head)

Type	1985	1986	1987	1988	1989	1990
Cattle	6,525.9	6,938.4	7,158.9	7,465.9	7,683.1	7,850.3
Buffalo	1993.4	2,043.7	2,089.8	2,106.6	2,139.5	2,169.0
Cow	162.7	184.6	216.4	222.2	252.6	269.1
Yak				1,300		1,433.6
Camel	53.0	50.4	47.5	47.2	47.5	46.3
Horse	1,108.1	1,098.8	1,069.1	1,054.0	1,029.6	1,017.4
Mule	497.2	511.3	524.8	536.6	539.1	549.4
Donkey	1,041.5	1,068.9	1,084.6	1,105.2	1,113.6	1,119.8
Pig	33,139.6	33,719.1	32,773.3	34,220.8	35,281.0	36,240.8
Goat	16,622.9	18,039.2	20,152.7	21,164.2	21,002.0	20,621.0

Source: *China Agricultural Yearbook, 1986-92.*

Table 4.10: ESTIMATION AND ANALYSIS OF LIVESTOCK METHANE EMISSIONS IN CHINA, 1990

Term	Cattle	Buffalo	Cow	Yak	Camel	Horse	Mule	Donkey	Pig	Goat	Total
Methane emission (Tg)	3.09	1.15	0.14	0.45	0.03	0.18	0.06	0.11	0.36	1.05	6.61
% of total	46.75	17.40	2.15	6.81	0.41	2.72	0.83	1.66	5.45	15.89	100

Table 4.11: POPULATION GROWTH AND PREDICTED DEMAND FOR MEAT PRODUCTS

Term	1990	2000	2010	2020
Total population (10,000)	119,303	133,341	143,023	150,225
Meat demand (10,000 tons)	2,857.00	3,842.21	4,576.74	5,558.33
Beef demand (10,000 tons)	125.60	208.82	295.96	416.80

4.14 The predicted demand for beef in the years 2000, 2010, and 2020 is shown in Table 4.11. The following sources and methodology were used:

(a) Source of data: *2020 Strategic Targets Research for Environmental Protection.*

(b) Based on existing supplies in 1990 and predictions by CAAS, by 2000 the average demand for meat per capita is projected to be 28.8 kg, in 2010 it will be 32 kg, and in 2020 it will be 37 kg.

(c) The projected demand for beef and mutton is based on studies done by CAAS. In 2000, beef will make up 8.77 percent of the meat demand; in 2010, it will make up 10.43 percent; and in 2020, 12.1 percent. The demand for beef will make up 62 percent of the total amount of beef and mutton demanded during different periods.

4.15 The predictions for methane emissions from cattle in the next 30 years are as follows:

(a) **High Scenario.** Based on the methane emission volume of beef per unit supplied in 1990, taking the amounts of beef demanded during different periods as a variable, not considering the application of emissions-controlling techniques or increases in animal husbandry productivity, predictions of CH_4 emission volume of cattle were carried out for different periods.

(b) **Medium Scenario.** The Ministry of Agriculture predicts that breed improvement for commercial animals and poultry will reach 50 percent by 2000 and 90 percent by 2020. Meanwhile, according to Agriculture Minister Liu Jiang, the rate of cattle breed improvement will reach 30 percent in China by the year 2000. Given the rates of projected cattle breed improvement: 30 percent in 2000; 50 percent in 2010; and 70 percent in 2020, the volume of CH_4 emissions will decrease per unit of meat product.

Use of ammoniated feed could potentially reach 10 percent by 2000, 15 percent by 2010, and 20 percent by 2020. Predictions for CH_4 emissions from cattle based on this projected use of ammoniated feed will serve as the low scenario for predicting cattle methane emissions.

(c) **Low Scenario.** The low scenario assumes that cattle breed improvement rates reach 40 percent, 70 percent, and 90 percent by 2000, 2010, and 2020 respectively, and that ammoniated feed is introduced in 15 percent, 20 percent and 25 percent of the areas in these respective years.

The coefficients used in the prediction are shown in Table 4.12. The predicted methane emissions from cattle for 2000, 2010, and 2020 are shown in Table 4.13.

4.16 The high scenario projects that the volume of CH_4 emissions from cattle will reach 14.54 Tg/yr, 3.01 times more than that in 1990. The medium scenario projects that there will be a net increase of 3.16 Tg/yr. The CH_4 emission volume of cattle in the next 30 years will be hard to control. Nevertheless, the trend can be slowed.

Table 4.12: Predicted Coefficient for Methane Emission of Livestock Cattle

Scenario		2000	2010	2020
Medium	Breed improvement rate (%)	30	50	70
	Ammoniated feed (%)	10	15	20
Low	Breed improvement rate (%)	40	70	90
	Ammoniated feed (%)	15	20	25

Table 4.13: Predicted Methane Emission of Livestock (Cattle) Tg/a

Scenario	1990	2000	2010	2020
High	4.832	7.290	10.326	14.542
Medium	4.832	5.968	7.032	7.998
Low	4.832	5.418	5.679	6.094

D. Prediction of Methane and Nitrous Oxide Emissions by Crop Residue Burning in China

4.17 Agricultural production in China has increased slowly in recent years (Table 4.14). Total grain output in 1990 was 44 million kg, falling short of that year's target of 45 million kg. In 1990, total agricultural crop output was 5,483.5 billion kg, of which 0.684 billion kg was crop straw. The authors estimate that the carbon produced by crop straw burning was 104.89 million tons in 1990. The volume of CH_4 produced was 0.88-1.64 Tg, and that of N_2O was 0.0082-0.0297 Tg (Table 4.15). Crop straw is a main source of fuel in the energy-short countryside; approximately 45 percent of straw output is burned for fuel.

Table 4.14: CROP PRODUCTION, 1984-91
Crop output (10,000 tons)

Crop	1984	1985	1986	1987	1988	1989	1990	1991
Rice	17,825.5	16,856.8	17,222.4	17,426.6	16,911.7	18,013.5	19,174.8	18,381.0
Wheat	8,781.5	8580.5	9,004.0	8,590.0	8,543.0	9,081.4	9,935.6	9,595.0
Tuber	2,847.5	2,603.6	2,533.7	2,822.3	2,722.8	2,714.7	2,768.1	2,716.0
Maize	7,341.0	6,382.6	7,085.6	7,924.2	7,735.0	7,893.0	9,882.3	9,877.0
Sorghum	771.5	561.0	538.4	542.8	584.7	450.0	568.2	494.3
Millet	702.5	597.7	454.0	453.8	452.1	374.7	456.4	342.4
Other grains	-	1,278.6	1,151.7	1,235.4	1,315.5	1,151.1	1,288.7	875.7
Soybean	969.5	1,050.0	1,161.4	1,218.4	1,160.2	1,022.8	1,110.0	971.3
Cotton	625.8	414.7	354.0	424.5	414.9	378.8	450.8	567.5
Oil-bearing	1,190.9	1,578.4	1,473.8	1,527.8	1,320.3	1,295.2	1,613.2	1,638.3
Bast-fiber	178.8	444.8	192.7	208.4	108.9	112.4	109.7	88.4
Sugar-bearing	4,780.3	6,046.8	5,852.5	5,550.4	6,187.5	5,803.8	7,214.5	8,418.7
Tobacco	178.9	242.5	170.7	194.3	273.1	283.0	262.7	267.0

Source: *Chinese Agricultural Yearbook, 1985-92.*

4.18 Meeting China's domestic demand for grain will be a major challenge in the coming decades. The Chinese government has assigned grain production priority in economic development, and it is likely to develop steadily in the coming decades.

4.19 With the increase in grain production, the output of crop straw will also rise. But the amount of straw burned will depend on how energy needs are addressed in the countryside. The amount burned in the next 30 years can be predicted on the basis of the predicted value (taken as a fixed value) of the crop output obtained by the Growth Model (Appendix C) and alternative rates of crop straw burning.

4.20 The interpolation method has been used to predict the output of major industrial crops as against the development targets contained in the Chinese Ministry of Agriculture's Mid- and Long-term Development Outline for Agro-Science and Technology. The calculated value and the targets for industrial crops are shown in Table 4.16.

Table 4.15: ESTIMATED EMISSION VOLUME OF METHANE AND NITROUS OXIDE FROM AGRO-CROP STRAW BURNING IN CHINA, 1990 (10,000 tons)

Term	Rice	Wheat	Tuber	Maize	Sorghum	Millet	Other grains	Soybean	Cotton	Oil-bearing	Bast	Sugar-bearing	Tobacco	Total
Crop Output	19,174.8	9,935.6	2,768.1	9,882.3	568.2	456.4	1,288.7	1,110.0	450.8	1,613.2	109.7	7,214.5	262.7	54,835.0
Straw Output	19,174.8	9,935.6	2,768.1	19,764.4	1,136.4	456.4	1,288.7	1,665.0	1,352.4	3,226.4	186.5	7,214.5	262.7	68,432.1
Amount of Carbon Burned	3,957.1	2,401.2	315.8	2,233.7	128.4	94.2	214.0	202.3	182.6	392.0	40.3	292.2	35.5	10,489.3
CH_4-C(L)	24.93	15.13	1.99	14.07	0.81	0.59	1.35	1.27	1.15	2.47	0.25	1.84	0.22	66.08
CH_4-C(H)	46.30	28.09	3.72	20.13	1.50	1.1	2.50	2.23	2.14	4.59	0.47	3.42	0.41	122.70
CH_4(L)	33.24	20.17	2.65	18.76	1.08	0.79	1.80	1.70	1.53	3.29	0.34	2.45	0.30	88.10
CH_4(H)	61.73	37.46	4.93	34.85	2.00	1.47	3.34	3.16	2.85	6.11	0.63	4.56	0.55	163.60
N_2O-N(L)	0.198	0.120	0.016	0.112	0.006	0.005	0.011	0.10	0.0091	0.020	0.0020	0.015	0.0018	0.52
N_2O-N(H)	0.722	0.432	0.057	0.402	0.023	0.017	0.039	0.036	0.033	0.071	0.0073	0.053	0.0064	1.89
N_2O(L)	0.311	0.189	0.025	0.176	0.010	0.007	0.017	0.016	0.014	0.031	0.0032	0.023	0.0028	0.82
N_2O(H)	1.119	0.679	0.089	0.632	0.036	0.027	0.061	0.057	0.052	0.11	0.011	0.083	0.01	2.97

Table 4.16: ESTIMATED OUTPUTS OF AGRO-CROPS AND STRAW (10,000 tons)

Year	Term	Rice	Wheat	Tuber	Maize	Sorghum	Millet	Other grains	Soybean	Cotton	Oil-bearing	Bast	Sugar-bearing	Tobacco	Total
2000	Crops	20,106.3	10,413.8	3,174.7	11,048.8	498.1	356	1,475.2	827.5	600	2,630	400	11,000	180	62,710.9
	Straw	20,106.3	10,413.8	3,174.7	22,097.6	996.1	355.9	1,475.9	1,241.2	1,800	5,260	680	11,000	180	78,781.5
2010	Crops	22,587.3	11,912.1	3,620.3	14,893.5	467.9	299.4	1,718.5	636.5	650	3,565	400	15,435	180	76,366.5
	Straw	22,587.3	11,912.1	3,620.3	29,787.0	935.9	299.4	1,718.5	956.8	1,950	7,130	680	15,436	180	97,191.2
2020	Crops	25,374.5	13,625.9	4,128.3	20,076.0	439.6	251.9	2,002.1	489.6	700	4,500	400	19,870	180	92,037.0
	Straw	25,374.5	13,625.9	4,128.3	40,152.0	879.2	251.9	2,002.1	736.4	2,100	9,000	680	19,870	180	118,978.4

Table 4.17: ESTIMATED EMISSION VOLUME OF METHANE AND NITROUS OXIDE FROM AGRO-CROP STRAW BURNING IN CHINA, 1990 (10,000 tons)

Term	Rice	Wheat	Tuber	Maize	Sorghum in 2000	Millet	Other grains	Soybean	Cotton	Oil-bearing	Bast in 2000	Sugar-bearing	Tobacco	Total
Year 2000														
Amount of Carbon Burned	4,149.3	2,294.99	362.27	2,497.43	112.56	73.47	244.9	150.72	243.5	638.9	147.1	445.6	24.2	11,384.9
CH_4-C(L)	26.14	14.46	2.28	15.73	0.71	0.46	1.54	0.95	1.53	4.03	0.91	2.81	0.15	71.7
CH_4-C(H)	48.55	26.85	4.24	29.22	1.32	0.86	2.87	1.76	2.85	7.48	1.72	5.22	0.28	133.22
CH_4(L)	34.85	19.28	3.04	20.98	0.95	0.62	2.06	1.27	2.03	5.36	1.24	3.74	0.2	95.62
CH_4(H)	64.73	35.8	5.65	38.96	1.76	1.15	3.82	2.35	3.79	9.96	2.3	6.95	0.38	177.6
N_2O-N(L)	0.207	0.115	0.018	0.125	0.006	0.004	0.012	0.008	0.0121	0.0326	0.0073	0.0229	0.0012	0.5711
N_2O-N(H)	0.747	0.413	0.065	0.45	0.02	0.013	0.044	0.027	0.0439	0.1157	0.0266	0.0808	0.0044	2.0504
N_2O(L)	0.326	0.18	0.028	0.196	0.009	0.006	0.019	0.012	0.0186	0.0505	0.0117	0.0351	0.0019	0.8938
N_2O(H)	1.174	0.649	0.102	0.706	0.032	0.021	0.069	0.043	0.0692	0.1793	0.4015	0.1266	0.0068	3.412
Year 2010														
Amount of Carbon Burned	4,661.3	2,442.4	413	3,366.5	105.6	61.7	285.5	116.1	262.9	866.3	147.1	625.3	24.2	13,377.9
CH_4-C(L)	29.37	15.39	2.6	21.21	0.67	0.39	1.8	0.73	1.66	5.46	0.91	3.94	0.15	83.37
CH_4-C(H)	54.54	28.58	4.83	39.39	1.24	0.72	3.34	1.36	3.08	10.35	1.72	7.32	0.28	156.75
CH_4(L)	39.16	20.52	3.47	28.28	0.89	0.52	2.4	0.98	2.03	7.27	1.24	5.24	0.2	112.2
CH_4(H)	72.72	38.1	6.44	52.52	1.65	0.96	4.45	1.81	4.10	13.50	2.30	6.15	0.38	305.08
N_2O-N(L)	0.233	0.122	0.021	0.168	0.005	0.003	0.014	0.006	0.0131	0.0442	0.0073	0.0321	0.0012	0.6699
N_2O-N(H)	0.839	0.44	0.074	0.606	0.019	0.011	0.051	0.021	0.4752	0.1569	0.0266	0.1134	0.0044	2.8375
N_2O(L)	0.366	0.192	0.032	0.265	0.008	0.005	0.022	0.009	0.0202	0.0685	0.0117	0.0492	0.0019	1.0505
N_2O(H)	1.318	0.691	0.117	0.952	0.03	0.017	0.081	0.033	0.0749	0.2431	0.4015	0.1776	0.0068	4.1429
Year 2020														
Amount of Carbon Burned	5,236.4	2,599.0	471.01	4,537.82	99.45	52.01	332.45	89.3	283.5	1,093.5	146.88	804.74	24.3	16,464.5
CH_4-C(L)	32.99	16.37	2.97	28.59	0.63	0.33	2.09	0.56	1.79	6.89	0.93	5.07	0.15	103.73
CH_4-C(H)	61.27	30.41	5.51	53.09	1.16	0.61	3.89	1.05	3.32	12.79	1.72	9.42	0.28	192.64
CH_4(L)	43.97	21.83	3.96	38.12	0.84	0.44	2.79	0.75	2.38	9.19	1.23	6.76	0.2	138.3
CH_4(H)	81.69	40.55	7.35	70.79	1.55	0.81	5.19	1.39	4.42	17.06	2.29	12.55	0.38	256.85
N_2O-N(L)	0.262	0.13	0.024	0.227	0.005	0.003	0.017	0.004	0.014	0.055	0.007	0.04	0.001	0.832
N_2O-N(H)	0.943	0.468	0.085	0.817	0.018	0.009	0.06	0.016	0.051	0.197	0.026	0.145	0.004	2.964
N_2O(L)	0.411	0.204	0.037	0.357	0.008	0.004	0.026	0.007	0.022	0.086	0.012	0.063	0.002	1.294
N_2O(H)	1.481	0.735	0.133	1.284	0.028	0.015	0.094	0.025	0.08	0.309	0.042	0.228	0.007	4.657

4.21 Predictions of CH_4 and N_2O emissions from crop straw burning are classified as follows:

(a) **High Scenario.** If the burning rate of crop straw remains at 60 percent, emissions of methane and nitrous oxide will increase along with the output of crop straw.

(b) **Medium Scenario.** As alternative energy sources are used in China's countryside, the rate of burning crop straw will decrease. The medium scenario assumes the international crop straw burning rate of 50 percent.

(c) **Low Scenario.** Although crop straw is burned mainly for fuel, there is the potential to increase its rate of utilization by using it as feed, changing the burning methods, and increasing the burning efficiency. The low scenario assumes that by 2020, the burning rate of crop straw will decline to 40 percent.

4.22 Table 4.15 shows the estimated volume of emissions from methane and nitrous oxide from crop straw burning in 1990. Predictions for high, medium, and low scenarios for the years 2000, 2010, and 2020 are shown in Tables 4.17, 4.18, and 4.19.

4.23 Each of the three scenarios predicts that the volume of CH_4 and N_2O emitted from crop straw burning in China will increase, but predictions vary with regard to quantity and speed. The medium scenario predicts an increase of 30.67 percent in the methane emission volume by 2020 over 1990. Controlling CH_4 and N_2O emissions from crop straw in the next 30 years will depend largely on how well rural energy needs can be met by sources other than crop straw.

Table 4.18a: ESTIMATED EMISSION OF CH_4 AND N_2O FROM AGRO-CROP STRAW BURNING: MEDIUM SCENARIO

Term	Rice	Wheat	Tuber	Maize	Sor-ghum	Millet	Other grains	Soy-bean
Year 2000								
Amount of C burned	3,872.74	2,349.00	338.09	2,330.88	105.07	68.56	228.74	140.75
CH_4-C(L)	24.40	14.80	2.13	14.69	0.66	0.43	1.44	0.89
CH_4-C(H)	45.31	27.48	3.96	27.27	1.23	0.80	2.68	1.65
CH_4(L)	32.53	19.73	2.84	19.58	0.88	0.58	1.92	1.18
CH_4(H)	60.42	36.64	5.27	36.36	1.64	1.07	3.57	2.20
$N_2$0-N(L)	0.194	0.117	0.017	0.117	0.005	0.003	0.011	0.007
$N_2$0-N(H)	0.697	0.423	0.061	0.420	0.019	0.012	0.041	0.025
$N_2$0(L)	0.304	0.185	0.027	0.183	0.008	0.005	0.018	0.011
$N_2$0(H)	1.095	0.664	0.096	0.659	0.030	0.019	0.065	0.040
Year 2010								
Amount of C burned	4,117.53	2,543.03	364.88	2,973.66	93.43	54.59	252.09	102.47
CH_4-C(L)	25.94	16.05	2.08	18.73	0.59	0.34	1.59	0.65
CH_4-C(H)	48.18	29.75	4.27	34.79	1.09	0.64	2.95	1.20
CH_4(L)	34.59	21.36	3.07	24.98	0.79	0.46	2.12	0.86
CH_4(H)	64.23	39.67	5.69	46.39	1.46	0.85	3.93	1.60
$N_2$0-N(L)	0.206	0.127	0.018	0.149	0.005	0.003	0.013	0.005
$N_2$0-N(H)	0.741	0.458	0.066	0.535	0.017	0.010	0.045	0.018
$N_2$0(L)	0.324	0.200	0.029	0.234	0.007	0.004	0.020	0.008
$N_2$0(H)	1.165	0.719	0.103	0.841	0.026	0.015	0.071	0.029
Year 2020								
Amount of C burned	4,363.81	2,744.26	392.54	3,781.52	82.81	43.32	277.01	74.36
CH_4-C(L)	27.49	17.29	2.47	23.82	0.52	0.27	1.75	0.47
CH_4-C(H)	51.06	32.11	4.59	44.24	0.97	0.51	3.24	0.87
CH_4(L)	36.66	23.05	3.30	31.77	0.70	0.36	2.33	0.63
CH_4(H)	68.08	42.81	6.21	58.99	1.29	0.68	4.32	1.16
$N_2$0-N(L)	0.218	0.137	0.020	0.189	0.004	0.002	0.014	0.004
$N_2$0-N(H)	0.785	0.494	0.071	0.681	0.015	0.008	0.050	0.013
$N_2$0(L)	0.343	0.216	0.031	0.297	0.007	0.003	0.022	0.006
$N_2$0(H)	1.234	0.776	0.111	1.070	0.023	0.012	0.078	0.021

Table 4.18b: Estimated Emission of CH_4 and N_2O from Agro-crop Straw Burning: Medium Scenario

Term	Cotton	Oil-bearing	Bast	Sugar-bearing	Tobacco	Total
Year 2000						
Amount of C burned	226.80	596.48	137.09	415.80	22.68	10,832.70
CH_4-C(L)	1.43	3.76	0.86	2.62	0.14	68.25
CH_4-C(H)	2.65	6.98	1.6	4.87	0.27	126.74
CH_4(L)	1.91	5.01	1.15	3.49	0.19	90.99
CH_4(H)	3.54	9.31	2.14	6.49	0.35	168.99
N_2O-N(L)	0.011	0.03	0.007	0.021	0.001	0.542
N_2O-N(H)	0.041	0.107	0.025	0.075	0.004	1.95
N_2O(L)	0.018	0.047	0.011	0.033	0.002	0.851
N_2O(H)	0.064	0.169	0.039	0.118	0.006	3.064
Year 2010						
Amount of C burned	232.54	765.23	129.74	552.22	21.47	12,202.87
CH_4-C(L)	1.47	4.82	0.82	3.48	0.14	76.88
CH_4-C(H)	2.72	8.95	1.52	6.46	0.25	142.77
CH_4(L)	1.95	6.43	1.09	4.64	0.18	102.5
CH_4(H)	3.63	11.94	2.02	8.62	0.34	190.37
N_2O-N(L)	0.012	0.038	0.006	0.028	0.001	0.61
N_2O-N(H)	0.042	0.138	0.023	0.099	0.004	2.197
N_2O(L)	0.018	0.06	0.01	0.043	0.002	0.959
N_2O(H)	0.066	0.216	0.037	0.156	0.006	3.452
Year 2020						
Amount of C burned	236.25	911.25	122.4	670.61	20.25	13,720.42
CH_4-C(L)	1.49	5.74	0.77	4.23	0.13	86.44
CH_4-C(H)	2.76	10.66	1.43	7.85	0.24	160.53
CH_4(L)	1.99	7.66	1.03	5.63	0.17	115.25
CH_4(H)	3.69	14.22	1.91	10.46	0.32	214.04
CH_4-C(L)	0.012	0.046	0.006	0.34	0.001	0.686
N_2O-N(H)	0.043	0.164	0.022	0.121	0.004	2.47
N_2O(L)	0.019	0.072	0.001	0.053	0.002	1.078
N_2O(H)	0.067	0.258	0.035	0.19	0.006	3.881

Table 4.19a: ESTIMATED EMISSION OF CH_4 AND N_2O FROM AGROCROP STRAW BURNING IN CHINA: LOW SCENARIO
(10,000 tons)

Term	Rice	Wheat	Tuber	Maize	Sor-ghum	Millet	Other grains	Soy-bean
Year 2000								
Amount of carbon burned	3,665.27	2,223.16	319.98	2,206.02	99.45	64.89	216.49	133.21
CH_4-C(L)	23.00	14.01	2.02	13.90	0.63	0.41	1.36	0.84
CH_4-C(H)	42.88	26.01	3.74	25.81	1.16	0.76	2.53	1.56
CH_4(L)	30.79	18.68	2.69	18.53	0.84	0.55	1.82	1.12
CH_4(H)	57.18	34.68	4.99	34.41	1.51	1.01	3.38	2.08
CH_4-C(L)	0.183	0.111	0.016	0.110	0.005	0.003	0.011	0.007
N_2O-N(H)	0.660	0.400	0.058	0.397	0.018	0.012	0.039	0.024
N_2O(L)	0.288	0.175	0.025	0.173	0.008	0.005	0.017	0.010
N_2O(H)	1.037	0.629	0.091	0.624	0.028	0.018	0.061	0.038
Year 2010								
Amount of carbon burned	3,573.7	2,207.16	316.69	2,580.91	81.09	47.38	218.79	88.94
CH_4-C(L)	22.51	13.91	2.00	16.26	0.51	0.30	1.38	0.56
CH_4-C(H)	41.81	25.82	3.71	30.20	0.95	0.55	2.56	1.04
CH_4(L)	30.02	18.54	2.66	21.68	0.68	0.40	1.84	0.75
CH_4(H)	55.76	34.43	4.94	40.26	1.27	0.74	3.41	1.39
CH_4-C(L)	0.179	0.110	0.016	0.129	0.004	0.002	0.011	0.004
N_2O-N(H)	0.643	0.397	0.057	0.465	0.015	0.009	0.039	0.016
N_2O(L)	0.281	0.173	0.025	0.203	0.006	0.004	0.017	0.007
N_2O(H)	1.011	0.624	0.090	0.730	0.023	0.013	0.062	0.025
Year 2020								
Amount of carbon burned	3,491.04	2,195.21	314.03	3,025.21	66.25	34.66	221.65	59.49
CH_4-C(L)	21.99	13.83	1.98	19.06	0.42	0.22	1.40	0.38
CH_4-C(H)	40.85	25.69	3.67	35.40	0.78	0.41	2.59	0.70
CH_4(L)	29.33	18.44	2.64	25.41	0.56	0.29	1.86	0.50
CH_4(H)	54.46	34.25	4.90	47.19	1.03	0.54	3.46	0.93
CH_4-C(L)	0.175	0.110	0.016	0.151	0.003	0.002	0.011	0.003
N_2O-N(H)	0.628	0.395	0.057	0.545	0.012	0.006	0.040	0.011
N_2O(L)	0.274	0.172	0.025	0.238	0.005	0.003	0.017	0.005
N_2O(H)	0.987	0.621	0.089	0.856	0.019	0.010	0.063	0.017

Table 4.19b: ESTIMATED EMISSION OF CH_4 AND N_2O FROM AGROCROP STRAW BURNING IN CHINA: LOW SCENARIO
(10,000 tons)

Term	Cotton	Oil-bearing	Bast	Sugar-bearing	Tobacco	Total
Year 2000						
Amount of carbon burned	214.65	564.53	129.74	393.53	21.47	10,252.38
CH_4-C(L)	1.35	3.56	0.82	2.48	0.14	64.59
CH_4-C(H)	2.51	6.61	1.52	4.6	0.25	119.95
CH_4(L)	1.80	4.74	1.09	3.31	0.18	86.12
CH_4(H)	3.35	8.81	2.02	6.14	0.34	159.94
CH_4-C(L)	0.011	0.028	0.006	0.02	0.001	0.513
N_2O-N(H)	0.039	0.102	0.023	0.071	0.004	1.845
N_2O(L)	0.017	0.044	0.010	0.031	0.002	0.806
N_2O(H)	0.061	0.16	0.037	0.111	0.006	2.900
Year 2010						
Amount of carbon burned	201.83	664.16	112.61	479.29	18.63	10,591.18
CH_4-C(L)	1.27	4.18	0.71	3.02	0.12	66.72
CH_4-C(H)	2.36	7.77	1.32	5.61	0.22	123.92
CH_4(L)	1.7	5.58	0.95	4.03	0.16	88.97
CH_4(H)	3.15	10.36	1.76	7.48	0.29	165.22
CH_4-C(L)	0.010	0.033	0.066	0.024	0.001	0.530
N_2O-N(H)	0.036	0.012	0.020	0.086	0.003	1.906
N_2O(L)	0.016	0.052	0.009	0.038	0.001	0.832
N_2O(H)	0.057	0.188	0.032	0.136	0.005	2.996
Year 2020						
Amount of carbon burned	189.00	729.00	97.92	536.49	16.2	10,976.34
CH_4-C(L)	1.19	4.59	0.62	3.38	0.1	69.15
CH_4-C(H)	2.21	3.53	1.15	6.28	0.19	128.42
CH_4(L)	1.59	6.12	0.82	4.51	0.14	92.2
CH_4(H)	2.95	11.37	1.53	8.37	0.25	171.23
CH_4-C(L)	0.009	0.036	0.005	0.027	0.001	0.549
N_2O-N(H)	0.034	0.131	0.018	0.097	0.003	1.976
N_2O(L)	0.015	0.057	0.008	0.042	0.001	0.862
N_2O(H)	0.053	0.206	0.028	0.152	0.005	3.105

5. CONCLUSION

5.1 In China, the main sources of greenhouse gas emissions (CH_4 and N_2O) come from agriculture. In 1990, the volume of CH_4 emissions from China's paddy fields was estimated at 14.3 Tg CH_4/a; that from livestock was 6.61 Tg CH_4/2; that from animal wastes was 2.03 Tg CH_4/a; and that from crop residue burning was 1.26 Tg CH_4/a. The combined emissions from these sources was 24.2 Tg CH_4/a, about 4.7 percent of the total global CH_4 emission volume. N_2O emissions from application of chemical fertilizers in 1990 were 0.02 Tg N_2O-N/a; those from crop straw burning were 0.012 Tg N_2O-N/a; the total emission volume was 0.032 Tg N_2O-N/a.

5.2 The volume of N_2O emissions from agricultural sources in China is far lower than that of other countries. Therefore, strategies for decreasing greenhouse gases by China's agricultural sector should stress the reduction of CH_4 emissions. The analyses of alternative means for reduction and the case studies done by the authors indicate that it is more practical to control CH_4 emissions from ruminant animals than from paddy fields. Thus, China should stress means for controlling CH_4 emissions from ruminant animals in its effort to reduce CH_4 emissions from agricultural sources.

5.3 The foregoing analysis has concluded that there are four measures for reducing greenhouse gas emissions that are most practical in terms of China's technology and economy:

(a) semidry cultivation and comprehensive utilization of rice paddies;

(b) intermittent irrigation of rice paddy fields;

(c) cattle breed improvement; and

(d) the use of ammoniated cattle feed.

5.4 These measures not only have great potential for reducing emissions, but could also greatly increase productivity. Farmers employing these methods would see higher economic returns within the same year. Some of the measures are now in use throughout China; others are in limited use. There is no doubt that, with support from the Chinese government and continued technical support at the local level, further progress will be made. Through application of these measures, China will contribute to the improvement of global climate conditions in the near future by controlling the CH_4 emissions from agricultural sources.

5.5 Predictions of CH_4 and N_2O emissions from agricultural sources for the years 2000, 2010, and 2020 have been based on a number of factors. If sound technical, economic, and regulatory policies are pursued, methane emissions from paddy fields will increase only slightly while emissions of nitrous oxide will be more marked. The combined total predicted emissions (high scenario) increase will range from three to five times current values. If productivity increases and controls are well implemented, the volume of CH_4 emissions from cattle will increase by approximately 30 percent. The CH_4 and N_2O emissions from crop straw burning will increase slightly as rural energy needs are met by alternative energy sources and the comprehensive utilization technique is improved.

5.6 Governments of several countries have attached importance to the problem of global climate change. Studies on technical measures and policies for reducing greenhouse gases are being conducted in many fields of research. China has just begun research on technical measures for reducing greenhouse gases from agricultural sources and has achieved preliminary results. However, more efforts are needed. The National Science and Technology Committee and the National Bureau of Environmental Protection should organize institutes and universities in a joint effort to address key research problems, strengthen international cooperation, and discover appropriate methods for reducing greenhouse gas emissions from agricultural sources.

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CATTLE BREED IMPROVEMENT IN CHINA: IMPLICATIONS FOR METHANE EMISSIONS REDUCTION

A. INTRODUCTION

1. Lingbi County is located in northeast Anhui Province on the Huaibei Plain. The county has a total population of 876,000. This rich agricultural area produces wheat, maize, soybeans, sorghum, cotton, and other miscellaneous crops. The county is also well suited to produce fodder and forage grass thus providing a firm foundation for the emerging commercial cattle industry. Since the 1950s, there have been efforts in Lingbi County to improve cattle breeds. Prior to that time, cattle were bred indiscriminately and, as a result, were inbred. A loss of desirable properties resulted. Efforts to improve cattle breeds culminated in 1981 with the introduction of Simmental cattle, the widespread adoption of artificial insemination (AI) via frozen semen, and a continued effort to improve local cattle by cross breeding.

2. The experiences of Lingbi County are not unique in China. In fact, there is a nationwide program to introduce Simmental via artificial insemination of frozen semen. The Simmental Cattle Breeding Committee of China was established to facilitate adoption of the program. Thus far, the program appears to have been a success, both financially and in terms of popular adoption.

3. Since 1981 in Lingbi County alone, more than 83,500 head of cattle have been bred using frozen semen from Simmental bulls. Conception rates have grown from 42.3 percent at the beginning of the program to 84.3 percent at present. In 1989, 61.4 percent of the total cattle under shed in the county were the product of these improved breeding practices.

4. Financially, the use of artificial insemination to introduce an improved breed can be justified. Although information from the Lingbi County experience does not permit analysis of all aspects of breed improvement, the evidence tends to indicate the viability of the program. Analysis using the Simmental improved crossbreeds in a commercial beef production setting is presented in section E. In addition, a brief analysis of Simmental calf production is presented in section G.

5. This analysis goes beyond the frozen semen program and its financial viability. Introducing cattle that have desirable properties such as enhanced weight gain allows the possibility of reducing methane emissions. Through their digestive process ruminant animals naturally emit large quantities of methane. Within the rumen, methane is produced as a by-product of the microbiological fermentation process that digests fibrous plant material [1]. As a greenhouse gas (GHG), methane contributes to global warming.

6. Simmental cattle, which utilize feed more completely than traditional local breeds (yellow cattle), emit more methane on a daily basis, but because of their increased weight gain, emit less methane on a per kilogram basis. Hence, the contribution to global greenhouse gas buildup will be lower. The following analysis will investigate this potential from a financial and economic point of view given the use of artificial insemination of frozen semen in China.

B. Adoption of Technology

7. In 1980, China imported 140 bulls from North America and Western Europe to be reared in 69 breeding stations throughout the country. Currently, there are 919 head of parent bulls that provide more than 1 million units of frozen semen. In addition to allowing producers to select breeds, artificial insemination avoids many of the shortcomings of natural service. For example, AI can prevent premature mating, fix the dates of breeding, and increase the conception rate. Moreover, freeze breeding produces better results than use of fresh semen. As a result, it has become the major method of breeding used in China.

8. Another advantage of frozen semen artificial insemination (FSAI) is its ease of mastery. Within about 15 days a veterinarian can master the skill and produce a conception rate of 50 to 85 percent. To enhance adoption, training programs have been introduced throughout China. Adoption of FSAI has reached 40 percent in the counties with pilot cattle improvement programs.

C. The Results of Breeding Stock Improvement

9. The following general results in breed improvements have been observed in the Simmental/FSAI program in Lingbi County.

(a) **Growth and Development**

- Birth weight: Compared with local cattle, birth weights of Simmental are higher by 83.2 percent for male calves and 94.2 percent for females.
- Six months of age: Local Simmental bulls are 42 percent heavier than local bulls; cows are 43 percent heavier.
- Twelve months of age: Local Simmental are heavier than local cattle by 27.2 percent for bulls and 23.5 percent for cows.
- Eighteen through 35 months of age: Similar weight-gain advantages are found.

- Local Simmental are well adapted to rearing conditions in China. They tend to be tolerant to the region's coarse fodder and are disease resistant.

- Local Simmental enter their first estrus cycle at about nine months of age and first breeding takes place between one and one and a half years of age. This is similar to the cycle of local cattle. Nonetheless, Simmental cows are larger and healthier, resulting in improved calving.

- When used as beasts of burden, Simmental are easy to train and are capable of beginning work at about one and a half years of age. This is six months before local cattle are ready. Their farming capacity is judged to be 55.8 percent greater than local cattle.

- Daily weight gain: Under routine shed rearing, local Simmental crossbreeds gain approximately 371 grams per day from 6 to 24 months of age while local cattle gain only 258 grams.

- Evaluation of slaughtered cattle: The average net weight of dressed meat from local Simmental is 151 kg or a 40.4 percent dress-out, while local cattle produce 115 kg, a 37.2 percent dress-out.

- Milk producing capacity: Local Simmental have a milk-producing term of 275 days and can produce 1,740.75 kg of fresh milk per head on average (i.e., 6.33 kg/day).

- Calf survival rate stands at 98 percent for Simmental crossbreeds.

D. The Frozen Semen Artificial Insemination Program in Lingbi County

10. Twenty-seven FSAI breeding stations have been set up throughout the county. Thus far, 50 technicians have been trained. The equipment for the stations include: a liquid nitrogen containing truck, 34 liquid nitrogen containers of different sizes, 10 desiccators and 27 microscopes. In addition, assistance has been provided to 14 households specializing in FSAI. A working fund of Y 80,000 was allocated for setting up the FSAI stations and for purchasing the needed equipment. Bonuses totaling Y 29,000 were given to finance demonstration of the program.

11. As the Simmental/FSAI program has matured the operation has become more efficient. For example, liquid nitrogen use has declined from 0.47 cubic liters per head at the beginning to 0.19 cubic liters. Semen cell consumption decreased from 3.8 cells per head to 2.5 cells.

E. Financial Analysis

12. This section will develop the analytical structure that will be used to assess the viability of the FSAI project. The objective will be to determine if the breeding program is financially viable.

Analytical Framework

13. Because technical cost and production data are limited, a partial budget analysis will be conducted. The analysis will be structured around the methane emissions of local yellow breeds versus improved Simmental crossbreeds. To this end, the analysis will be limited to cattle with fully developed rumen. Based on work in Dingxing, Dolberg concluded this occurs after four months [2]. The current study is limited further to commercial beef production. As a result, the cattle will be held from the beginning of the fifth month until they reach 450 kg. This is similar to the structure used by Finlayson to analyze cattle feed trials in Henan and Hebei [3]. (See section G for analysis of the FSAI program's impact on cattle production up to age five months.)

14. To avoid having to value inputs for which information is not available one head of the local cattle is assumed to be purchased at the end of its fourth month and held until it weighs 450 kg. This takes approximately 46 additional months. At this time another four month old cow is purchased and raised until it weighs 450 kg.

15. The same procedure is used for the Simmental crossbreeds. They take approximately 29 months to mature. It is assumed that the monthly requirements for labor, stalls, medical attention, etc., are the same for both animals. Thus, the incremental costs of raising the Simmental crossbreeds over the yellow cattle for these inputs is zero.

16. The analysis was extended for 60 months.1/ At this time it was assumed that both the Simmental and yellow cows on hand were sold at their current weight.

17. The inputs that vary between the two cases are the feed and the number and weight of the four-month-old cows. During 60 months, two Simmental cattle can be fattened to 450 kilograms and one to 164 kilograms, but during this time only one yellow breed can be fully fattened and one to 203 kilograms. In addition, the Simmental crossbreeds purchased as inputs are heavier than their yellow cattle counterparts owing to greater weight gain during the first four months. They weighed 129.12 kg while the local yellow breeds weighed only 91.4 kg (Table 1). The purchase and sale price of Y 3.6/kg found by Finlayson [3] was used for the analysis.

1/ Because the times to slaughter of the two different breeds vary, an analysis was conducted for 229 months. At this time a local breed matured and a Simmental cross-breed had just matured at the end of the 228th month. This final Simmental was held the additional month and sold at the heavier weight. The internal rates of return for this longer analysis are very close to those presented below. As a result, only the abridged analysis is presented.

Table 1: BEGINNING WEIGHT AND MONTHLY WEIGHT GAIN (kilograms)

	Yellow cattle	Simmental	Incremental
Four month weight (Beginning)	91.42	129.12	37.70
Monthly weight gain	7.84	11.28	3.44

18. The feed requirement per kilogram weight gain for the Simmental crossbreeds is 7.25 kg versus 9.38 kg for the yellow cattle (Table 2). Feed, which is a combination of improved feed and straw, is valued at Y 0.28 per kg.

Table 2: FEED COSTS PER KILOGRAM WEIGHT GAIN AND PURCHASE PRICE PER KILOGRAM

	Unit	Yellow cattle		Simmental		Incremental	
Item	price (Y)	Use (kg)	Costs (Y)	Use (kg)	Costs (Y)	Use (kg)	Costs (Y)
Feed	0.28	9.38	2.63	7.25	2.03	-2.89	-0.81
Purchase	3.6						

19. Methane emissions, based on findings in Lingbi County, are estimated for the two breeds and converted to a per kilogram weight gain basis (Table 3). The benefits of avoided methane emissions are not valued.2/ The analysis will be limited to assessing the cost of methane emission abatement that must be allocated to Simmental crossbreed production to justify fattening these cows in place of the yellow breeds.

20. There are four possible sources of revenue for the cattle: milk, labor (as beasts of burden), dung/urine, and slaughter (includes meat, hides, and internal organs).

2/ It should be noted, however, that methane on a 100-year horizon is 21 times more potent than the most abundant greenhouse gas, carbon dioxide. The convention is to put greenhouse gas emissions on a CO_2 basis. Comparing the two on an extended horizon allows consideration of the varying atmospheric lifetimes of these two greenhouse gases.

Table 3: METHANE EMISSIONSÄKILOGRAMS/KILOGRAM WEIGHT GAIN AND KILOGRAMS/HEAD

	Yellow cattle	Simmental	Incremental
Methane (kg/kg wgt. gain)	0.47	0.39	-0.08
Methane (kg/head—4 mos to slaughter)	169	125	-44

In China, the latter three are the most important sources.3/ This analysis concerns itself exclusively with revenue for slaughter. In this regard, the analysis is aimed at the developing commercial meat industry. The dung/urine quantities for yellow and Simmental cattle are similar, therefore this revenue source cancels in the incremental analysis.4/

21. In an analysis of animals for either milking or as beasts of burden, one would need to value the milk and/or work value because the quantities vary between the two breeds. The current analysis can be viewed as a lower bound for animals that are used in either of these endeavors, since the Simmental crossbreeds are superior in both activities when compared to yellow cattle.

22. The partial budget framework compares a with-project case to a without-project case. The Simmental crossbreeds are the with project case and the local yellow breeds are the without project case. From these, incremental costs and revenues that result from the adoption of the project are calculated. The net present values for costs, revenues, and their net are calculated for the incremental case.

Financial Results

23. Tables 4 through 6 list the with (Simmental crossbreeds), without (yellow cattle), and incremental cash flows. Assuming an opportunity cost of capital of 12 percent, the net present value of the breeding project's incremental contribution is Y 464.29, and the internal rate of return is 74.29 percent.

24. This indicates a viable project even before the global impacts of methane emissions are considered. That is to say, valuing the reduced methane emissions is not

3/ Milk production is not a major factor in Lingbi County. There are no facilities for collecting and storing fresh milk. Also, milk consumption is not traditional in this area nor in China generally; from 1988 to 1990, dairy cattle comprised only 2.5 percent of total cattle numbers in while beef/draft comprised 76.2 percent [5].

4/ The annual excretion of dung is 730 kg/head and 3,650 kg/head for urine. This amount of urine is equivalent to approximately 11 kg of urea. Urea is valued at about 1.1 yuan per kg [3].

necessary to yield a positive net present value when an opportunity cost of capital of 12 percent is used.

25. These results can be considered lower bounds in that the weight gains were based on F1 Simmental crossbreeds. With successive generations the results from Lingbi County appear to be more favorable. The following sensitivity analysis will investigate the financial impact when weight gains improve.

Sensitivity Analysis

26. The critical difference between the financial situations facing production of the two breeds is the daily weight gain. A sensitivity analysis of alternative weight gains for the Simmental cattle was conducted. In addition, the value of the incremental feed consumption was also varied. Both were increased and decreased 10 and 20 percent. Switching values were also calculated. The results are presented in Table 7.

27. The analysis is very stable relative to feed costs. The results seem to be more sensitive to changes in weight gain. It should be noted, however, that a 30 percent reduction in the weight gains of Simmental crossbreeds reduces their gains to approximately the same level as yellow breeds. Therefore, 20 to 30 percent reductions in the Simmental weight gain are substantial. With this in mind, the analysis is more stable than first appearances indicate.

Table 4: Cost, Revenue, Methane Emissions, and Weight Gain: Simmental Cattle

Month	Purchase (Y)	Feed (Y)	Revenue (Y)	Methane (kg)	Weight gain (kg)
0	464.83	0.00	0.00		
1	0.00	22.90	0.00	4.3992	11.28
2	0.00	22.90	0.00	4.3992	11.28
3	0.00	22.90	0.00	4.3992	11.28
4	0.00	22.90	0.00	4.3992	11.28
5	0.00	22.90	0.00	4.3992	11.28
6	0.00	22.90	0.00	4.3992	11.28
7	0.00	22.90	0.00	4.3992	11.28
8	0.00	22.90	0.00	4.3992	11.28
9	0.00	22.90	0.00	4.3992	11.28
10	0.00	22.90	0.00	4.3992	11.28
11	0.00	22.90	0.00	4.3992	11.28
12	0.00	22.90	0.00	4.3992	11.28
13	0.00	22.90	0.00	4.3992	11.28
14	0.00	22.90	0.00	4.3992	11.28
15	0.00	22.90	0.00	4.3992	11.28
16	0.00	22.90	0.00	4.3992	11.28
17	0.00	22.90	0.00	4.3992	11.28
18	0.00	22.90	0.00	4.3992	11.28
19	0.00	22.90	0.00	4.3992	11.28
20	0.00	22.90	0.00	4.3992	11.28
21	0.00	22.90	0.00	4.3992	11.28
22	0.00	22.90	0.00	4.3992	11.28
23	0.00	22.90	0.00	4.3992	11.28
24	0.00	22.90	0.00	4.3992	11.28
25	0.00	22.90	0.00	4.3992	11.28
26	0.00	22.90	0.00	4.3992	11.28
27	0.00	22.90	0.00	4.3992	11.28
28	0.00	22.90	0.00	4.3992	11.28
29	464.83	22.90	1740.00	4.3992	11.28
30	0.00	22.90	0.00	4.3992	11.28
31	0.00	22.90	0.00	4.3992	11.28
32	0.00	22.90	0.00	4.3992	11.28
33	0.00	22.90	0.00	4.3992	11.28
34	0.00	22.90	0.00	4.3992	11.28
35	0.00	22.90	0.00	4.3992	11.28
36	0.00	22.90	0.00	4.3992	11.28
37	0.00	22.90	0.00	4.3992	11.28
38	0.00	22.90	0.00	4.3992	11.28
39	0.00	22.90	0.00	4.3992	11.28
40	0.00	22.90	0.00	4.3992	11.28
41	0.00	22.90	0.00	4.3992	11.28
42	0.00	22.90	0.00	4.3992	11.28
43	0.00	22.90	0.00	4.3992	11.28

cont'd....

Table 4: (cont'd)

Month	Purchase (Y)	Feed (Y)	Revenue (Y)	Methane (kg)	Weight gain (kg)
44	0.00	22.90	0.00	4.3992	11.28
45	0.00	22.90	0.00	4.3992	11.28
46	0.00	22.90	0.00	4.3992	11.28
47	0.00	22.90	0.00	4.3992	11.28
48	0.00	22.90	0.00	4.3992	11.28
49	0.00	22.90	0.00	4.3992	11.28
50	0.00	22.90	0.00	4.3992	11.28
51	0.00	22.90	0.00	4.3992	11.28
52	0.00	22.90	0.00	4.3992	11.28
53	0.00	22.90	0.00	4.3992	11.28
54	0.00	22.90	0.00	4.3992	11.28
55	0.00	22.90	0.00	4.3992	11.28
56	0.00	22.90	0.00	4.3992	11.28
57	464.83	22.90	1,740.00	4.3992	11.28
58	0.00	22.90	0.00	4.3992	11.28
59	0.00	22.90	0.00	4.3992	11.28
60	0.00	22.90	710.98	4.3992	11.28
Total	1,394.49	1,374.00	4,190.98	263.95	676.80
PV	1,066.11	1,019.28	2,655.46	195.81	502.07

F. ENVIRONMENTAL IMPACT

28. This portion of the analysis investigates the project's impact on pollution abatement. Since pollution abatement is a social issue, the financial analysis must be adjusted for price distortions. The adjustments will follow recent recommendations by the China Department [6] recommendations calling for a 12 discount rate (used throughout the analysis) and a standard conversion factor of 0.8. This moderate conversion factor reflects the extensive dismantling of price distortions in China. The purchase price, feed cost, and revenues are adjusted by the standard conversion factor. Since this factor is applied to both costs and revenues, the impact on the internal rate of return is unchanged and the present value of costs, revenues, and net benefits are reduced by the conversion factor. This being the case the economic tables are not repeated here. Based on the economic values, the costs, revenues, and net project benefits are reformulated per ton of CO_2 emissions equivalent, Table 8.5/ This use of CO_2 equivalency facilitates comparisons to other studies. The per-ton benefit figure is of greatest interest, but caution should be used in its interpretation. It is the economic benefit from engaging in the project, not the health or other benefits from GHG reduction. For this project the value is positive. Thus,

5/ Since the methane emissions reduction is on a per kilogram weight gain basis, the values are first expressed on a per kilogram weight basis. They are then divided by a factor for the CO_2-equivalent emissions per kilogram weight gain.

Table 5: Cost, Revenue, Methane Emissions and Weight Gain: Yellow Cattle

Month	Purchase (Y)	Feed (Y)	Revenue (Y)	Methane (kg)	Weight gain (kg)
0	329.04	0.00	0.00		
1	0.00	20.59	0.00	3.6848	7.84
2	0.00	20.59	0.00	3.6848	7.84
3	0.00	20.59	0.00	3.6848	7.84
4	0.00	20.59	0.00	3.6848	7.84
5	0.00	20.59	0.00	3.6848	7.84
6	0.00	20.59	0.00	3.6848	7.84
7	0.00	20.59	0.00	3.6848	7.84
8	0.00	20.59	0.00	3.6848	7.84
9	0.00	20.59	0.00	3.6848	7.84
10	0.00	20.59	0.00	3.6848	7.84
11	0.00	20.59	0.00	3.6848	7.84
12	0.00	20.59	0.00	3.6848	7.84
13	0.00	20.59	0.00	3.6848	7.84
14	0.00	20.59	0.00	3.6848	7.84
15	0.00	20.59	0.00	3.6848	7.84
16	0.00	20.59	0.00	3.6848	7.84
17	0.00	20.59	0.00	3.6848	7.84
18	0.00	20.59	0.00	3.6848	7.84
19	0.00	20.59	0.00	3.6848	7.84
20	0.00	20.59	0.00	3.6848	7.84
21	0.00	20.59	0.00	3.6848	7.84
22	0.00	20.59	0.00	3.6848	7.84
23	0.00	20.59	0.00	3.6848	7.84
24	0.00	20.59	0.00	3.6848	7.84
25	0.00	20.59	0.00	3.6848	7.84
26	0.00	20.59	0.00	3.6848	7.84
27	0.00	20.59	0.00	3.6848	7.84
28	0.00	20.59	0.00	3.6848	7.84
29	0.00	20.59	0.00	3.6848	7.84
30	0.00	20.59	0.00	3.6848	7.84
31	0.00	20.59	0.00	3.6848	7.84
32	0.00	20.59	0.00	3.6848	7.84
33	0.00	20.59	0.00	3.6848	7.84
34	0.00	20.59	0.00	3.6848	7.84
35	0.00	20.59	0.00	3.6848	7.84
36	0.00	20.59	0.00	3.6848	7.84
37	0.00	20.59	0.00	3.6848	7.84
38	0.00	20.59	0.00	3.6848	7.84
39	0.00	20.59	0.00	3.6848	7.84
40	0.00	20.59	0.00	3.6848	7.84
41	0.00	20.59	0.00	3.6848	7.84
42	0.00	20.59	0.00	3.6848	7.84

cont'd...

Table 5: (cont'd)

Month	Purchase (Y)	Feed (Y)	Revenue (Y)	Methane (kg)	Weight gain (kg)
43	0.00	20.59	0.00	3.6848	7.84
44	0.00	20.59	0.00	3.6848	7.84
45	0.00	20.59	0.00	3.6848	7.84
46	329.04	20.59	1740.00	3.6848	7.84
47	0.00	20.59	0.00	3.6848	7.84
48	0.00	20.59	0.00	3.6848	7.84
49	0.00	20.59	0.00	3.6848	7.84
50	0.00	20.59	0.00	3.6848	7.84
51	0.00	20.59	0.00	3.6848	7.84
52	0.00	20.59	0.00	3.6848	7.84
53	0.00	20.59	0.00	3.6848	7.84
54	0.00	20.59	0.00	3.6848	7.84
55	0.00	20.59	0.00	3.6848	7.84
56	0.00	20.59	0.00	3.6848	7.84
57	0.00	20.59	0.00	3.6848	7.84
58	0.00	20.59	0.00	3.6848	7.84
59	0.00	20.59	0.00	3.6848	7.84
60	0.00	20.59	851.59	3.6848	7.84
Total	658.08	1235.40	2591.59	221.09	470.40
PV	531.91	916.46	1554.16	164.01	348.96

Table 6: INCREMENTAL COST, REVENUE, NET BENEFITS, METHANE EMISSIONS AND WEIGHT GAIN

Month	Purchase (Y)	Feed (Y)	Revenue (Y)	Net benefits (Y)	Methane (kg/kg weight gain)	Weight gain (kg)
0	135.79	0.00	0.00	-135.792		
1	0.00	2.31	0.00	-2.31	-0.08	3.44
2	0.00	2.31	0.00	-2.31	-0.08	3.44
3	0.00	2.31	0.00	-2.31	-0.08	3.44
4	0.00	2.31	0.00	-2.31	-0.08	3.44
5	0.00	2.31	0.00	-2.31	-0.08	3.44
6	0.00	2.31	0.00	-2.31	-0.08	3.44
7	0.00	2.31	0.00	-2.31	-0.08	3.44
8	0.00	2.31	0.00	-2.31	-0.08	3.44
9	0.00	2.31	0.00	-2.31	-0.08	3.44
10	0.00	2.31	0.00	-2.31	-0.08	3.44
11	0.00	2.31	0.00	-2.31	-0.08	3.44
12	0.00	2.31	0.00	-2.31	-0.08	3.44
13	0.00	2.31	0.00	-2.31	-0.08	3.44
14	0.00	2.31	0.00	-2.31	-0.08	3.44
15	0.00	2.31	0.00	-2.31	-0.08	3.44
16	0.00	2.31	0.00	-2.31	-0.08	3.44
17	0.00	2.31	0.00	-2.31	-0.08	3.44
18	0.00	2.31	0.00	-2.31	-0.08	3.44
19	0.00	2.31	0.00	-2.31	-0.08	3.44
20	0.00	2.31	0.00	-2.31	-0.08	3.44
21	0.00	2.31	0.00	-2.31	-0.08	3.44
22	0.00	2.31	0.00	-2.31	-0.08	3.44
23	0.00	2.31	0.00	-2.31	-0.08	3.44
24	0.00	2.31	0.00	-2.31	-0.08	3.44
25	0.00	2.31	0.00	-2.31	-0.08	3.44
26	0.00	2.31	0.00	-2.31	-0.08	3.44
27	0.00	2.31	0.00	-2.31	-0.08	3.44
28	0.00	2.31	0.00	-2.31	-0.08	3.44
29	464.83	2.31	1,740.00	1,272.86	-0.08	3.44
30	0.00	2.31	0.00	-2.31	-0.08	3.44
31	0.00	2.31	0.00	-2.31	-0.08	3.44
32	0.00	2.31	0.00	-2.31	-0.08	3.44
33	0.00	2.31	0.00	-2.31	-0.08	3.44
34	0.00	2.31	0.00	-2.31	-0.08	3.44
35	0.00	2.31	0.00	-2.31	-0.08	3.44
36	0.00	2.31	0.00	-2.31	-0.08	3.44
37	0.00	2.31	0.00	-2.31	-0.08	3.44
38	0.00	2.31	0.00	-2.31	-0.08	3.44
39	0.00	2.31	0.00	-2.31	-0.08	3.44
40	0.00	2.31	0.00	-2.31	-0.08	3.44
41	0.00	2.31	0.00	-2.31	-0.08	3.44
42	0.00	2.31	0.00	-2.31	-0.08	3.44

cont'd...

Table 6: (cont'd)

Month	Purchase (Y)	Feed (Y)	Revenue (Y)	Net benefits (Y)	Methane (kg/kg weight gain)	Weight gain (kg)
43	0.00	2.31	0.00	-2.31	-0.08	3.44
44	0.00	2.31	0.00	-2.31	-0.08	3.44
45	0.00	2.31	0.00	-2.31	-0.08	3.44
46	-329.04	2.31	-1,740.00	-1,413.27	-0.08	3.44
47	0.00	2.31	0.00	-2.31	-0.08	3.44
48	0.00	2.31	0.00	-2.31	-0.08	3.44
49	0.00	2.31	0.00	-2.31	-0.08	3.44
50	0.00	2.31	0.00	-2.31	-0.08	3.44
51	0.00	2.31	0.00	-2.31	-0.08	3.44
52	0.00	2.31	0.00	-2.31	-0.08	3.44
53	0.00	2.31	0.00	-2.31	-0.08	3.44
54	0.00	2.31	0.00	-2.31	-0.08	3.44
55	0.00	2.31	0.00	-2.31	-0.08	3.44
56	0.00	2.31	0.00	-2.31	-0.08	3.44
57	464.83	2.31	1,740.00	1,272.86	-0.08	3.44
58	0.00	2.31	0.00	-2.31	-0.08	3.44
59	0.00	2.31	0.00	-2.31	-0.08	3.44
60	0.00	2.31	-140.62	-142.926	-0.08	3.44
Totals	736.41	138.60	1,599.38	724.37	-4.80	206.40
PV	534.19	102.82	1,101.30	464.29	-3.56	153.11
IRR(%)				74.29		

Table 7: SENSITIVITY ANALYSIS FOR THE SIMMENTAL CROSS-BREEDING PROGRAM

		Feed costs	Weight gain
Change Rate (%)			
-20	NPV (yuan)	484.85	48.60
	IRR (%)	76.62	24.70
-10	NPV (yuan)	474.57	217.22
	IRR (%)	75.45	53.02
0	NPV (yuan)	464.29	464.29
	IRR (%)	74.29	74.29
+10	NPV (yuan)	454.00	662.27
	IRR (%)	73.12	92.93
+20	NPV (yuan)	443.72	845.20
	IRR (%)	71.94	106.29
Switching Values			
551%	NPV (yuan)	0	
	IRR (%)	12	
-23.00	NPV (yuan)		0
	IRR (%)		12

the project makes sense on economic grounds before environmental considerations are made.6/ That is to say, the environmental objectives of this project can be accomplished at negative cost.

Table 8: PROJECT COSTS, REVENUES, AND NET BENEFITS ON A PER-TON CO_2 REDUCTION BASIS

	Costs	Revenue	Net Benefits
	--------- (per ton CO_2 reduction) ---------		
Y/ton CO_2 equivalent	1,981.13	3,425.08	1,443.95
US dollars/ton CO_2 equivalent	$330.19	$570.85	$240.66

Note: Calculations were made based on present values at a 12% discount rate and the assumption that methane is 21 times more potent as a greenhouse gas than carbon dioxide. Dollar values were converted at Y 6 per dollar.

G. FINANCIAL ANALYSIS TO FOUR MONTHS

29. A proper analysis of the frozen semen artificial insemination program would require investment cost data, operating costs and revenues. Very little of this information is available. In addition, the life of investment items (the truck, tanks, etc.) is not available. Therefore, in lieu of a formal analysis, the ability for the program to cover a generous estimate of variable costs will be investigated.

30. It is estimated that the frozen semen artificial insemination program that has been used in Lingbi County to introduce Simmental cattle into the population costs approximately Y 23.4 per impregnated cow. This should be viewed as an upper bound over the long term, because up to Y 3.9 of this figure represents the cost of extension efforts associated with introducing the technique. Also, part of this figure represents an estimate of depreciation charges. This, too, will result in an overstatement from a project analysis point of view.

31. Table 9 contains incremental cost and revenue information associated with caring for an impregnated cow and the resulting calf. The assumption is that a yellow cow and Simmental crossbreed cow are purchased just prior to conception. The animals are held until the calves are four months old. At that time, cows and calves are sold. The costs that are assumed to vary between the yellow cow and the Simmental crossbreed are

6/ Had the value been negative, then one would need to compare the amount required to bring project benefits to zero with the health and other benefits from pollution abatement. If the amount needed to elevate the project benefits to zero were less than or equal to the benefits from the project's emissions reduction, then the project could be justified on environmental grounds.

feed and artificial insemination charges. The revenues vary by the different weight gains of the cows and calves. The calves are assumed to grow to the four month weights used in the main analysis (91.42 kg and 129.12 kg, respectively), and the cows are assumed to have monthly gains half that of cows in the main analysis (3.92 kg/mo and 5.64 kg/mo, respectively).

32. As shown in Table 9, the higher costs of breeding Simmental cattle are offset by the added revenue. This is a conservative analysis in that no allowance is made for the differential conception rate and calf survival. These both favor the Simmental crossbreeds.

33. The question that remains unanswered is whether the insemination fee provides enough revenue to justify the program. The data are not available to answer this question properly, but the FSAI charge could increase almost sevenfold before the present value would equal zero with a discount rate of 12 percent. Therefore, there appears to be ample room to cover FSAI costs.

Table 9: Partial Budget Analysis of Yellow Cattle versus Simmental Cross-Breeds Conception and Raising to Age Four Months

	Yellow cattle		Simmental		Incremental		
Month	Costs	Revenues	Costs	Revenues	Costs	Revenues	Net
1	1,100.59	0.00	1,126.30	0.00	25.71	0.00	-25.71
2	20.59	0.00	22.90	0.00	2.31	0.00	-2.31
3	20.59	0.00	22.90	0.00	2.31	0.00	-2.31
4	20.59	0.00	22.90	0.00	2.31	0.00	-2.31
5	20.59	0.00	22.90	0.00	2.31	0.00	-2.31
6	20.59	0.00	22.90	0.00	2.31	0.00	-2.31
7	20.59	0.00	22.90	0.00	2.31	0.00	-2.31
8	20.59	0.00	22.90	0.00	2.31	0.00	-2.31
9	20.59	0.00	22.90	0.00	2.31	0.00	-2.31
10	20.59	0.00	22.90	0.00	2.31	0.00	-2.31
11	24.71	0.00	27.48	0.00	2.77	0.00	-2.77
12	24.71	0.00	27.48	0.00	2.77	0.00	-2.77
13	24.71	1,592.50	27.48	1,808.78	2.77	216.29	213.52
Total	1,360.02	1,592.50	1,414.84	1,808.78	54.82	216.29	161.47
PV	1,330.10	1,399.27	1,382.53	1,589.31	52.43	190.04	137.62
IRR (%)							186.4

H. CONCLUSION

34. The Simmental/FSAI program in China appears to be a financial success and in addition, it yields global environmental benefits by attacking a major source of anthropogenic methane emissions. Worldwide, domestic livestock contribute 28 percent of these emissions [7], and China's share of this total is approximately 6 percent [8]. Much of China's share comes from 100 million head of cattle [5]. By 2010 this number is predicted to grow to 169 million head [5]. Of these 169 million head, 84 percent fall into the category discussed in this study. With the potential to cut methane emissions by almost 11 percent per animal through breed improvement, the global environmental benefits are likely to be substantial.

35. To better assess the viability of the breeding program, more information is needed on the FSAI stations. Specifically, the cost and life of the equipment involved needs to be better identified. This preliminary analysis, however, indicates that the Simmental/FSAI program increases productivity and reduces green house gas emissions. These are key criteria established for evaluating agricultural sector environmental projects, and they are accomplished without specific regard to the methane reducing capability. That is to say, this preliminary analysis indicates that the project is likely to be a success even before the beneficial environmental effects are considered.

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ANALYSIS OF USING AMMONIATED STRAW AS A SOURCE OF IMPROVED FEED FOR CATTLE

A. Introduction

1. Chinese agriculture produces as a by-product abundant supplies of wheat and rice straw. This low quality feed source is typically used as a maintenance feed for ruminant animals—principally cattle. There is the opportunity, however, to improve the nutritional quality of straw substantially. By adding urea, a source of nitrogen, the daily weight gains of cattle can be significantly enhanced. This urea-treated straw is referred to as ammoniated feed. The use of this feed in China is limited, but growing. In 1991, seven provinces each produced more than 100,000 tons of ammoniated feed, Table 1 [1].

2. The weight gains associated with ammoniated feed result in an additional benefit—reduced methane emissions per kilogram of weight gain. Methane is a natural by-product of ruminant animals. Within the rumen, methane is produced during the microbiological fermentation process needed to digest fibrous plant material [2]. As a potent green house gas (21 times more powerful than carbon dioxide), methane contributes to the potential we face for global warming.

3. The purpose of this study is to investigate the financial and economic viability of producing ammoniated feed for cattle. The potential methane reductions will also be considered. The experience of Huaiyang County and an experiment at the Hebei Animal Husbandry Research Institute will form the basis of the following analysis [3 and 4]. Huaiyang County is located in Henan Province. Huaiyang producers have been active in the use of ammoniated feed, and the county is thus among the ten pioneers of this process in China.

4. The next section will describe the ammoniation process. A discussion of the benefits will follow. Then the financial and economic analysis will be presented.

B. The Process

5. Production of ammoniated feed is a very simple process. The straw is first cut to 2 to 3 centimeter lengths. It is then mixed with urea and water. The mixture is placed in an ammoniation tank, stirred, pressed and covered with a plastic film and allowed to ferment. The resulting ammoniated feed is often combined with an improved feed such as cotton seed cake to further enhance the nutritional quality.

6. The recommended ratio of urea, water and straw varies. For 100 kg of straw the urea treatment can range from 3 to 5 kg, and the water can vary from 35 to

Table 1: AVAILABLE GREEN FORAGE AND IMPROVED STRAW, 1991

Province/region	Green forage/silage ('000 tons green matter)	Ammoniated straw ('000 tons dry matter)
National Total	41,390	3,710
Hebei	1,385	195
Shanxi	350	170
Inner Mongolia	1,549	273
Other	390	45
Subtotal N	3,674	683
Jilin	1,355	504
Heilongjiang	1,850	500
Other	1,788	31
Subtotal NE	4,993	1,035
Shandong	4,975	1,281
Other	9,673	160
Subtotal MLYR	14,648	1,441
Henan	1,882	306
Other	800	29
Subtotal S	2,682	335
Subtotal SW	9,858	40
Shaanzi	1,052	101
Other	2,483	75
Subtotal W	3,535	176
State farms	2,000	0

Source: [1]

80 kg. In the current analysis, 5 kg of urea will be assumed. The amount of time that the mixture remains covered also varies. It ranges from approximately two to four weeks.

The upper bound will be used in this study along with the assumption that the ammoniated feed is allowed to sit uncovered for a couple days, bringing the treatment time to one month. These assumptions will lead to conservative financial and economic estimates in that they either increase treatment costs in the case of urea levels or reduce the quantity of feed that can be produced in the case of treatment time.

C. Benefits

7. In the past, energy in areas such as Huaiyang County was in short supply. As a result straw was used as a fuel. Today, however, the bulk of straw not used in animal production goes to waste. Oftentimes, the straw is burned in the field to allow planting of the next crop [5 and 6]. In an attempt to better use this by-product, the ammoniated feed experiment began in 1986 [3]. By 1992, the amount of ammoniated feed in Henan Province had grown from the 1991 value of 306,000 tons to more than 1 million tons [6]. The number of ammoniation containers in Huaiyang County alone had grown to 33,000 by the end of 1992 [3].

8. The project has been supported through subsidized credit and the availability of urea at the official, discounted price [6]. These have certainly benefited initiation of the program, but once introduced, farmers have had no difficulty nor hesitancy in continuing treatments with their own resources and without subsidization. To reflect this sustainable situation, the analysis that follows will use market prices for urea.

9. The daily weight gains that can be expected from treated and untreated wheat straw are provided in Table 2. Both situations include feeding of 1.5 kg of cotton seed cake and a mineral supplement [4]. Use of ammoniated feed results in an 85 percent increase in daily weight gain. This large gain drives the financial and economic analyses that follow.

10. Because of increased feed intake, cattle fed treated straw emit more methane on a daily basis, but because of increased daily weight gain, emissions are lower per kilogram of live weight gain (Table 3). The reduced emissions amount to a 38.5 percent decline per kilogram weight gain. This and the reduced burning of straw in the field constitute the major environmental benefits of ammoniating feed.7/

D. Financial Analysis

11. A partial budget analysis will be used to evaluate the with and without treatment projects. In a similar study, Finalyson assumed that cattle were fattened from an initial weight of 180 kg to a slaughter weight of 450 kg [6].8/ This procedure will

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7/ These gains are partially offset by any soil nutritional benefits that result from leaving the straw in the field.

8/ The period from birth to 180 kilograms will not be analyzed. It is assumed that the methane benefits of ammoniated feed would be minimal during this period.

Table 2: DAILY WEIGHT GAINS

	With treatment	Without treatment	Incremental
Daily gain, gms	644±21	348±13	296

Table 3: METHANE EMISSIONS—PER DAY AND PER KILOGRAM LIVE WEIGHT GAIN

	With Treatment	Without treatment	Incremental
Per Day (Kg)	.21	.18	.03
Per Kg Weight Gain	.32	.52	-.20

Source: Per Kg Weight Gain from [7].

also be assumed in this study. Further, it will be assumed that one animal after another will be fed treated straw during the life of the investment. The costs and benefits of this situation will be compared to feeding untreated straw to one cow after another. By setting the analysis up in this fashion certain costs and benefits are the same under the with- and without-treatment scenarios. As a result they cancel in the incremental portion of the analysis. Examples of these costs include the cost of the shed and a portion of the labor expenses. Benefits that cancel include the dung and urine.9/

12. Treatment requires a cement ammoniation container. The container costs Y 150 and is projected to last five years. The ideal treatment quantity is 300 kg [3]. The cost of ammoniating 300 kg of straw is Y 19.05 (Table 4). To determine the feed requirements a daily analysis was conducted over the five year life of the ammoniation container. Daily figures were aggregated into monthly values. For the animals receiving treated and untreated straw Table 5 contains the end of month weight, monthly straw

9/ There are four basic sources of revenue from cattle production: dung/urine, meat and by-products, milk, and as beasts of burden. Only the values of meat and by-products will be considered in this study. Dung and urine values should be approximately the same in the with and without treatment scenarios. Milk production is a minor aspect of China's cattle industry. By ignoring this aspect and revenues from using cattle as beasts of burden, China's emerging meat production industry becomes the focus.

intake, methane emissions, and month of sale.10/ During the period, 14,000 kg of treated straw are fed compared to 8,300 kg of untreated straw. Four cows are fattened to 450 kg and an additional animal to 200 kg using treated straw while only two cows are fattened to 450 kg and one to 275 kg using untreated straw. In order to produce the required ammoniated feed 46.88 treatments are required. This amounts to 0.78 treatments per month. The monthly costs are shown in Table 6.

13. The cattle are assumed to be purchased and sold for Y 3.60 per kg [6]. In addition to the per kilogram value, the hides provide a revenue source. Estimates of their value range from Y 120 to 200. A value of 120 is used here (Table 7).

Table 4: Cost per Treatment of 300 Kg of Straw

	Economic CF	yuan/unit	Use	Cost (yuan)
Plastic (kg)	1	8	0.25	2.00
Urea (kg)	1	1.1	15	16.50
Labor (day)	1	1.1	0.5	0.55
Total				19.05

Note: One half kg of plastic is required per treatment and lasts two treatments.

14. The with treatment, without treatment and incremental financial cash flows are presented in Tables 8-10, respectively. The present values are calculated using a 12 percent discount rate. The internal rate of return for the incremental cash flow is 110 percent.11/ This level and the low investment costs help to explain why farmers are embracing this new technology so readily.

10/ The values in Table 5 represent end-of-month levels. The analysis is done on a daily basis but, for clarity, presented monthly. As a result, the end-of-month weight for the months when an animal is sold varies. This reflects the fact that the animals are purchased when the previous animal reaches 450 kg which occurs at different times within the sale month. A month is assumed to be 365÷12 days. The daily quantity of straw fed varies with the animal's weight (2.5% of the animal's weight with the treatment and 2.1 percent without the treatment[4]).

11/ To determine the uniqueness of the internal rate of return estimate, alternative discount rates and the resulting present values were calculated. Over a wide range of rates there was no indication of multiple solutions for the internal rate of return.

Table 5: END OF MONTH WEIGHT, STRAW INTAKE, METHANE EMISSIONS, AND TIMING OF SALES—WITH AND WITHOUT STRAW TREATMENT

Month	With treatment				Without treatment			
	Weight kg	Straw kg	Methane kg	Animal sold	Weight kg	Straw kg	Methane kg	Animal sold
0	180.00	0.00	0.00		180.00	0.00	0.00	
1	199.59	121.24	6.27		190.59	118.37	5.50	
2	219.18	159.24	6.27		201.17	125.13	5.50	
3	238.77	174.14	6.27		211.76	131.89	5.50	
4	258.36	189.03	6.27		222.34	138.66	5.50	
5	277.95	203.93	6.27		232.93	145.42	5.50	
6	297.54	218.83	6.27		243.52	152.18	5.50	
7	317.13	233.73	6.27		254.10	158.94	5.50	
8	336.72	248.63	6.27		264.69	165.71	5.50	
9	356.31	263.53	6.27		275.28	172.47	5.50	
10	375.90	278.43	6.27		285.86	179.23	5.50	
11	395.50	293.32	6.27		296.45	186.00	5.50	
12	415.09	308.22	6.27		307.03	192.76	5.50	
13	434.68	323.12	6.27		317.62	199.52	5.50	
14	184.27	235.35	6.27	X	328.21	206.28	5.50	
15	203.86	147.58	6.27		338.79	213.05	5.50	
16	223.45	162.48	6.27		349.38	219.81	5.50	
17	243.04	177.38	6.27		359.96	226.57	5.50	
18	262.63	192.28	6.27		370.55	233.33	5.50	
19	282.22	207.18	6.27		381.14	240.10	5.50	
20	301.81	222.08	6.27		391.72	246.86	5.50	
21	321.40	236.98	6.27		402.31	253.62	5.50	
22	340.99	251.87	6.27		412.90	260.38	5.50	
23	360.58	266.77	6.27		423.48	267.15	5.50	
24	380.17	281.67	6.27		434.07	273.91	5.50	
25	399.76	296.57	6.27		444.65	280.67	5.50	
26	419.35	311.47	6.27		185.24	101.66	5.50	X
27	438.94	326.37	6.27		195.83	61.50	5.50	
28	188.53	238.60	6.27	X	206.41	64.92	5.50	
29	208.12	150.83	6.27		217.00	68.33	5.50	
30	227.71	165.73	6.27		227.58	71.75	5.50	
31	247.30	180.63	6.27		238.17	75.17	5.50	
32	266.90	195.52	6.27		248.76	78.58	5.50	
33	286.49	210.42	6.27		259.34	82.00	5.50	
34	306.08	225.32	6.27		269.93	85.42	5.50	
35	325.67	240.22	6.27		280.52	88.83	5.50	
36	345.26	255.12	6.27		291.10	92.25	5.50	
37	364.85	270.02	6.27		301.69	95.67	5.50	
38	384.44	284.92	6.27		312.27	99.08	5.50	
39	404.03	299.81	6.27		322.86	102.50	5.50	
40	423.62	314.71	6.27		333.45	105.92	5.50	
41	443.21	329.61	6.27		344.03	109.33	5.50	

cont'd....

Table 5: (cont'd)

Month	With treatment Weight kg	Straw kg	Methane kg	Animal sold	Without treatment Weight kg	Straw kg	Methane kg	Animal sold
42	192.80	241.84	6.27	X	354.62	112.75	5.50	
43	212.39	154.07	6.27		365.20	116.17	5.50	
44	231.98	168.97	6.27		375.79	119.59	5.50	
45	251.57	183.87	6.27		386.38	123.00	5.50	
46	271.16	198.77	6.27		396.96	126.42	5.50	
47	290.75	213.67	6.27		407.55	129.84	5.50	
48	310.34	228.57	6.27		418.14	133.25	5.50	
49	329.93	243.47	6.27		428.72	136.67	5.50	
50	349.52	258.36	6.27		439.31	140.09	5.50	
51	369.11	273.26	6.27		449.89	143.50	5.50	
52	388.70	288.16	6.27		190.48	103.35	5.50	X
53	408.30	303.06	6.27		201.07	63.19	5.50	
54	427.89	317.96	6.27		211.65	66.61	5.50	
55	447.48	332.86	6.27		222.24	70.02	5.50	
56	197.07	245.09	6.27	X	232.82	73.44	5.50	
57	216.66	157.32	6.27		243.41	76.86	5.50	
58	236.25	172.22	6.27		254.00	80.27	5.50	
59	255.84	187.12	6.27		264.58	83.69	5.50	
60	275.43	202.01	6.27	X	275.17	87.11	5.50	X
Total		14,063.54	376.14			8,356.74	330.28	

Table 6: NUMBER AND COST OF THE TREATMENTS REQUIRED DURING THE INVESTMENT PERIOD

Straw Treated (kg)	14,063
Straw per Treatment (kg)	300
Treatments	46.88
Treatments per Month	0.78
Cost/Month	14.88

Sensitivity Analysis

15. The items that vary between the with and without project situation include the following: investment cost, feed treatment cost, weight gain and the resulting

Table 7: Production Indicators With and Without Feed Treatment.

	Economic CF	With treatment	Without treatment	Incremental
Sales (kg)		2,075.43	1,175.17	900.26
Sales Price (yuan)	1.00	3.60	3.60	0.00
Income Sources				
Sales income (yuan)		7,471.55	4,230.61	3,240.94
Hides (yuan)	1.00	480.00	240.00	240.00
Total income (yuan)		7,951.55	4,470.61	3,480.94

Table 8:

Month	Invest	Treatment	Purchase	Revenues	Methane
45	0.00	14.88	0.00	0.00	6.27
46	0.00	14.88	0.00	0.00	6.27
47	0.00	14.88	0.00	0.00	6.27
48	0.00	14.88	0.00	0.00	6.27
49	0.00	14.88	0.00	0.00	6.27
50	0.00	14.88	0.00	0.00	6.27
51	0.00	14.88	0.00	0.00	6.27
52	0.00	14.88	0.00	0.00	6.27
53	0.00	14.88	0.00	0.00	6.27
54	0.00	14.88	0.00	0.00	6.27
55	0.00	14.88	0.00	0.00	6.27
56	0.00	14.88	648.00	1740.00	6.27
57	0.00	14.88	0.00	0.00	6.27
58	0.00	14.88	0.00	0.00	6.27
59	0.00	14.88	0.00	0.00	6.27
60	0.00	0.00	0.00	991.54	6.27
Total	150.00	893.00	3240.00	7951.54	376.14
PV	148.51	669.08	2475.24	5518.75	281.82

frequency of sale. Sensitivity analysis has been conducted for each of these. In addition, the purchase/sale price will be varied. The results are presented in Tables 11 and 12.

16. The cost of treatment, investment cost, and the purchase/sale price are varied plus and minus 10 and 20 percent (Table 11). The switching values are also provided. With all three variables, the present values and internal rates of return are very

Table 8: FINANCIAL CASH FLOW WITH TREATMENT

Month	Invest	Treatment	Purchase	Revenues	Methane
0	150.00	14.88	648.00	0.00	0.00
1	0.00	14.88	0.00	0.00	6.27
2	0.00	14.88	0.00	0.00	6.27
3	0.00	14.88	0.00	0.00	6.27
4	0.00	14.88	0.00	0.00	6.27
5	0.00	14.88	0.00	0.00	6.27
6	0.00	14.88	0.00	0.00	6.27
7	0.00	14.88	0.00	0.00	6.27
8	0.00	14.88	0.00	0.00	6.27
9	0.00	14.88	0.00	0.00	6.27
10	0.00	14.88	0.00	0.00	6.27
11	0.00	14.88	0.00	0.00	6.27
12	0.00	14.88	0.00	0.00	6.27
13	0.00	14.88	0.00	0.00	6.27
14	0.00	14.88	648.00	1,740.00	6.27
15	0.00	14.88	0.00	0.00	6.27
16	0.00	14.88	0.00	0.00	6.27
17	0.00	14.88	0.00	0.00	6.27
18	0.00	14.88	0.00	0.00	6.27
19	0.00	14.88	0.00	0.00	6.27
20	0.00	14.88	0.00	0.00	6.27
21	0.00	14.88	0.00	0.00	6.27
22	0.00	14.88	0.00	0.00	6.27
23	0.00	14.88	0.00	0.00	6.27
24	0.00	14.88	0.00	0.00	6.27
25	0.00	14.88	0.00	0.00	6.27
26	0.00	14.88	0.00	0.00	6.27
27	0.00	14.88	0.00	0.00	6.27
28	0.00	14.88	648.00	1740.00	6.27
29	0.00	14.88	0.00	0.00	6.27
30	0.00	14.88	0.00	0.00	6.27
31	0.00	14.88	0.00	0.00	6.27
32	0.00	14.88	0.00	0.00	6.27
33	0.00	14.88	0.00	0.00	6.27
34	0.00	14.88	0.00	0.00	6.27
35	0.00	14.88	0.00	0.00	6.27
36	0.00	14.88	0.00	0.00	6.27
37	0.00	14.88	0.00	0.00	6.27
38	0.00	14.88	0.00	0.00	6.27
39	0.00	14.88	0.00	0.00	6.27
40	0.00	14.88	0.00	0.00	6.27
41	0.00	14.88	0.00	0.00	6.27
42	0.00	14.88	648.00	1740.00	6.27
43	0.00	14.88	0.00	0.00	6.27
44	0.00	14.88	0.00	0.00	6.27

cont'd....

Table 9: FINANCIAL CASH FLOW WITHOUT TREATMENT

Month	Invest	Treatment	Purchase	Revenues	Methane
0	0.00	0.00	648.00	0.00	0.00
1	0.00	0.00	0.00	0.00	5.50
2	0.00	0.00	0.00	0.00	5.50
3	0.00	0.00	0.00	0.00	5.50
4	0.00	0.00	0.00	0.00	5.50
5	0.00	0.00	0.00	0.00	5.50
6	0.00	0.00	0.00	0.00	5.50
7	0.00	0.00	0.00	0.00	5.50
8	0.00	0.00	0.00	0.00	5.50
9	0.00	0.00	0.00	0.00	5.50
10	0.00	0.00	0.00	0.00	5.50
11	0.00	0.00	0.00	0.00	5.50
12	0.00	0.00	0.00	0.00	5.50
13	0.00	0.00	0.00	0.00	5.50
14	0.00	0.00	0.00	0.00	5.50
15	0.00	0.00	0.00	0.00	5.50
16	0.00	0.00	0.00	0.00	5.50
17	0.00	0.00	0.00	0.00	5.50
18	0.00	0.00	0.00	0.00	5.50
19	0.00	0.00	0.00	0.00	5.50
20	0.00	0.00	0.00	0.00	5.50
21	0.00	0.00	0.00	0.00	5.50
22	0.00	0.00	0.00	0.00	5.50
23	0.00	0.00	0.00	0.00	5.50
24	0.00	0.00	0.00	0.00	5.50
25	0.00	0.00	0.00	0.00	5.50
26	0.00	0.00	648.00	1740.00	5.50
27	0.00	0.00	0.00	0.00	5.50
28	0.00	0.00	0.00	0.00	5.50
29	0.00	0.00	0.00	0.00	5.50
30	0.00	0.00	0.00	0.00	5.50
31	0.00	0.00	0.00	0.00	5.50
32	0.00	0.00	0.00	0.00	5.50
33	0.00	0.00	0.00	0.00	5.50
34	0.00	0.00	0.00	0.00	5.50
35	0.00	0.00	0.00	0.00	5.50
36	0.00	0.00	0.00	0.00	5.50
37	0.00	0.00	0.00	0.00	5.50
38	0.00	0.00	0.00	0.00	5.50
39	0.00	0.00	0.00	0.00	5.50
40	0.00	0.00	0.00	0.00	5.50
41	0.00	0.00	0.00	0.00	5.50
42	0.00	0.00	0.00	0.00	5.50
43	0.00	0.00	0.00	0.00	5.50
44	0.00	0.00	0.00	0.00	5.50

cont'd....

Table 9: (cont'd)

Month	Invest	Treatment	Purchase	Revenues	Methane
45	0.00	0.00	0.00	0.00	5.50
46	0.00	0.00	0.00	0.00	5.50
47	0.00	0.00	0.00	0.00	5.50
48	0.00	0.00	0.00	0.00	5.50
49	0.00	0.00	0.00	0.00	5.50
50	0.00	0.00	0.00	0.00	5.50
51	0.00	0.00	0.00	0.00	5.50
52	0.00	0.00	648.00	1740.00	5.50
53	0.00	0.00	0.00	0.00	5.50
54	0.00	0.00	0.00	0.00	5.50
55	0.00	0.00	0.00	0.00	5.50
56	0.00	0.00	0.00	0.00	5.50
57	0.00	0.00	0.00	0.00	5.50
58	0.00	0.00	0.00	0.00	5.50
59	0.00	0.00	0.00	0.00	5.50
60	0.00	0.00	0.00	990.61	5.50
Total	0.00	0.00	1944.00	4470.61	330.28
PV	0.00	0.00	1519.34	2896.82	245.01

stable. An increase in the treatment cost of 219 percent is required to reduce the internal rate of return to the discount rate. For the investment level and purchase/sale price a 634 percent increase and 55.35 percent drop, respectively, are required.

17. For weight gains, the experimental range found by Dolberg (see Table 2 above) is used in place of the arbitrary plus and minus 10 and 20 percent variation used above. First, the upper bound for the weight gain of the cattle fed ammoniated feed and the lower bound of the gain for the cattle not fed ammoniated feed are used. This is assumed to be the maximum weight-gain spread between the two options. For this situation the internal rate of return climbs to 118.60 percent.

18. When the upper-bound nontreatment weight gain is used along with the lower-bound treatment gain, the internal rate of return drops to 89.21 percent. For the internal rate of return to drop to the discount rate (12 percent), the weight gain gap has to narrow by almost 50 percent.

19. For each of the variables analyzed, a large change is required to reach its switching value. This result will be reflected in the economic analysis in the next section. As adjustments are made to selected prices to reflect price distortions, one can expect that the impact on the present values and internal rate of return will be relatively small. This is because the corrections for distortions that need to be made are small relative to the appropriate switching value.

Table 10: INCREMENTAL FINANCIAL CASH FLOW

Month	Investment	Treatment	Purchase	Revenue	Net benefit	Methane
0	150.00	14.88	0.00	0.00	-164.88	0.00
1	0.00	14.88	0.00	0.00	-14.88	0.76
2	0.00	14.88	0.00	0.00	-14.88	0.76
3	0.00	14.88	0.00	0.00	-14.88	0.76
4	0.00	14.88	0.00	0.00	-14.88	0.76
5	0.00	14.88	0.00	0.00	-14.88	0.76
6	0.00	14.88	0.00	0.00	-14.88	0.76
7	0.00	14.88	0.00	0.00	-14.88	0.76
8	0.00	14.88	0.00	0.00	-14.88	0.76
9	0.00	14.88	0.00	0.00	-14.88	0.76
10	0.00	14.88	0.00	0.00	-14.88	0.76
11	0.00	14.88	0.00	0.00	-14.88	0.76
12	0.00	14.88	0.00	0.00	-14.88	0.76
13	0.00	14.88	0.00	0.00	-14.88	0.76
14	0.00	14.88	648.00	1,740.00	1,077.12	0.76
15	0.00	14.88	0.00	0.00	-14.88	0.76
16	0.00	14.88	0.00	0.00	-14.88	0.76
17	0.00	14.88	0.00	0.00	-14.88	0.76
18	0.00	14.88	0.00	0.00	-14.88	0.76
19	0.00	14.88	0.00	0.00	-14.88	0.76
20	0.00	14.88	0.00	0.00	-14.88	0.76
21	0.00	14.88	0.00	0.00	-14.88	0.76
22	0.00	14.88	0.00	0.00	-14.88	0.76
23	0.00	14.88	0.00	0.00	-14.88	0.76
24	0.00	14.88	0.00	0.00	-14.88	0.76
25	0.00	14.88	0.00	0.00	-14.88	0.76
26	0.00	14.88	-648.00	-1740.00	-1106.88	0.76
27	0.00	14.88	0.00	0.00	-14.88	0.76
28	0.00	14.88	648.00	1740.00	1077.12	0.76
29	0.00	14.88	0.00	0.00	-14.88	0.76
30	0.00	14.88	0.00	0.00	-14.88	0.76
31	0.00	14.88	0.00	0.00	-14.88	0.76
32	0.00	14.88	0.00	0.00	-14.88	0.76
33	0.00	14.88	0.00	0.00	-14.88	0.76
34	0.00	14.88	0.00	0.00	-14.88	0.76
35	0.00	14.88	0.00	0.00	-14.88	0.76
36	0.00	14.88	0.00	0.00	-14.88	0.76
37	0.00	14.88	0.00	0.00	-14.88	0.76
38	0.00	14.88	0.00	0.00	-14.88	0.76
39	0.00	14.88	0.00	0.00	-14.88	0.76
40	0.00	14.88	0.00	0.00	-14.88	0.76
41	0.00	14.88	0.00	0.00	-14.88	0.76
42	0.00	14.88	648.00	1740.00	1077.12	0.76
43	0.00	14.88	0.00	0.00	-14.88	0.76
44	0.00	14.88	0.00	0.00	-14.88	0.76

cont'd....

Table 10: (cont'd)

Month	Investment	Treatment	Purchase	Revenue	Net benefit	Methane
45	0.00	14.88	0.00	0.00	-14.88	0.76
46	0.00	14.88	0.00	0.00	-14.88	0.76
47	0.00	14.88	0.00	0.00	-14.88	0.76
48	0.00	14.88	0.00	0.00	-14.88	0.76
49	0.00	14.88	0.00	0.00	-14.88	0.76
50	0.00	14.88	0.00	0.00	-14.88	0.76
51	0.00	14.88	0.00	0.00	-14.88	0.76
52	0.00	14.88	-648.00	-1740.00	-1106.88	0.76
53	0.00	14.88	0.00	0.00	-14.88	0.76
54	0.00	14.88	0.00	0.00	-14.88	0.76
55	0.00	14.88	0.00	0.00	-14.88	0.76
56	0.00	14.88	648.00	1740.00	1077.12	0.76
57	0.00	14.88	0.00	0.00	-14.88	0.76
58	0.00	14.88	0.00	0.00	-14.88	0.76
59	0.00	14.88	0.00	0.00	-14.88	0.76
60	0.00	0.00	0.00	0.93	0.93	0.76
Total	150.00	893.00	1,296.00	3,480.93	1,141.93	45.82
PV	148.51	669.08	955.90	2,567.29	793.79	33.99
IRR					109.86	

Table 12: Sensitivity Analysis for the Ammoniated Feed Project: Weight Gain

Weight gains (without vs. with)	Range		
.335 vs. .665	.330 (+11.49%)	NPV (yuan)	957.94
		IRR (%)	118.60
.348 vs. .644	.296	NPV (yuan)	793.79
		IRR (%)	109.86
.361 vs. .623	.262 (-11.49 %)	NPV (yuan)	620.14
		IRR (%)	89.21
Switching Value			
.348 vs. .4995	.1515 (-48.82%)	NPV (yuan)	0.00
		IRR (%)	12.00

Table 11: Sensitivity Analysis for the Ammoniated Feed Project: Treatment Cost, Investment Level and Purchase/Sale Price

Change rate (%)		Treatment cost	Investment level	Purchase/ sale price
-20	NPV (yuan)	927.60	823.49	506.91
	IRR	123.63	122.78	84.36
-10	NPV (yuan)	860.70	808.64	650.35
	IRR	116.75	116.01	97.85
0	NPV (yuan)	793.79	793.79	793.79
	IRR	109.86	109.86	109.86
+10	NPV (yuan)	726.88	778.94	937.22
	IRR	102.93	104.24	120.69
+20	NPV (yuan)	659.97	764.08	1,080.66
	IRR	95.93	99.08	130.57
Switching values				
Treatment cost		+219%		
Investment level			+634%	
Purchase/sale price			-55.35%	

E. Economic Analysis

20. To ensure that valuation of the with and without treatment options adequately reflect societal resource availability this section will adjust the financial prices for distortions. The adjustments will follow recent recommendations by the China Department [8]. These recommendations call for a 12 percent test discount rate, a 0.8 conversion factor for rural labor, a standard conversion factor of 0.8, and not applying conversion factors or fixed shadow prices to specific tradable commodities. These recommendations reflect the extensive dismantling of price distortions in China. By the end of 1992, ninety percent of consumer goods (in terms of sales value) had been deregulated and price controls for 80 percent of industrial raw materials had been lifted [8].

21. The adjustments are reflected in Tables 13-18. The impacts of these adjustments are modest. For example, the internal rate of return drops from 110 to 92 percent. Since the beneficial environmental effects due to the reduced methane emissions and any straw burning that would be avoided are not factored into this rate, the figure is a conservative estimate.

Table 13: COST PER TREATMENT OF 300 KG OF STRAW

	Economic CF	yuan/unit	Use (kg)	Cost (yuan)
Plastic (kg)	1	8	0.25	2.00
Urea (kg)	1	1.1	15	16.50
Labor (day)	0.8	0.88	0.5	0.44
Total				18.94

Table 14: PRODUCTION INDICATORS WITH AND WITHOUT FEED TREATMENT

	Economic CF	With project (Y)	Without project (Y)
Sales		2,075.43	1,175.17
Sales price	0.80	2.88	2.88
Sales income		5,977.24	3,384.49
Hides	0.80	384.00	192.00
Total		6,361.24	3,576.49

Table 15: ESTIMATED BREAKDOWN OF INVESTMENT COST OF AMMONIATION TANK

	Economic CF	Cost (yuan)
Labor	0.80	18.00
Cement	1.00	7.50
Misc. materials	0.80	96.00
Total		121.50

Note: This is an estimate of the cost breakdown. Total cost comes from Finalyson.

22. The present value of the project's incremental economic costs, revenues and

Table 16: ECONOMIC CASH FLOW WITH TREATMENT

Month	Invest	Treatment	Purchase	Revenues	Methane
0	121.50	14.80	518.40	0.00	0.00
1	0.00	14.80	0.00	0.00	6.27
2	0.00	14.80	0.00	0.00	6.27
3	0.00	14.80	0.00	0.00	6.27
4	0.00	14.80	0.00	0.00	6.27
5	0.00	14.80	0.00	0.00	6.27
6	0.00	14.80	0.00	0.00	6.27
7	0.00	14.80	0.00	0.00	6.27
8	0.00	14.80	0.00	0.00	6.27
9	0.00	14.80	0.00	0.00	6.27
10	0.00	14.80	0.00	0.00	6.27
11	0.00	14.80	0.00	0.00	6.27
12	0.00	14.80	0.00	0.00	6.27
13	0.00	14.80	0.00	0.00	6.27
14	0.00	14.80	518.40	1392.00	6.27
15	0.00	14.80	0.00	0.00	6.27
16	0.00	14.80	0.00	0.00	6.27
17	0.00	14.80	0.00	0.00	6.27
18	0.00	14.80	0.00	0.00	6.27
19	0.00	14.80	0.00	0.00	6.27
20	0.00	14.80	0.00	0.00	6.27
21	0.00	14.80	0.00	0.00	6.27
22	0.00	14.80	0.00	0.00	6.27
23	0.00	14.80	0.00	0.00	6.27
24	0.00	14.80	0.00	0.00	6.27
25	0.00	14.80	0.00	0.00	6.27
26	0.00	14.80	0.00	0.00	6.27
27	0.00	14.80	0.00	0.00	6.27
28	0.00	14.80	518.40	1392.00	6.27
29	0.00	14.80	0.00	0.00	6.27
30	0.00	14.80	0.00	0.00	6.27
31	0.00	14.80	0.00	0.00	6.27
32	0.00	14.80	0.00	0.00	6.27
33	0.00	14.80	0.00	0.00	6.27
34	0.00	14.80	0.00	0.00	6.27
35	0.00	14.80	0.00	0.00	6.27
36	0.00	14.80	0.00	0.00	6.27
37	0.00	14.80	0.00	0.00	6.27
38	0.00	14.80	0.00	0.00	6.27
39	0.00	14.80	0.00	0.00	6.27
40	0.00	14.80	0.00	0.00	6.27
41	0.00	14.80	0.00	0.00	6.27
42	0.00	14.80	518.40	1392.00	6.27
43	0.00	14.80	0.00	0.00	6.27
44	0.00	14.80	0.00	0.00	6.27

cont'd....

Table 16: (cont'd)

Month	Invest	Treatment	Purchase	Revenues	Methane
45	0.00	14.80	0.00	0.00	6.27
46	0.00	14.80	0.00	0.00	6.27
47	0.00	14.80	0.00	0.00	6.27
48	0.00	14.80	0.00	0.00	6.27
49	0.00	14.80	0.00	0.00	6.27
50	0.00	14.80	0.00	0.00	6.27
51	0.00	14.80	0.00	0.00	6.27
52	0.00	14.80	0.00	0.00	6.27
53	0.00	14.80	0.00	0.00	6.27
54	0.00	14.80	0.00	0.00	6.27
55	0.00	14.80	0.00	0.00	6.27
56	0.00	14.80	518.40	1392.00	6.27
57	0.00	14.80	0.00	0.00	6.27
58	0.00	14.80	0.00	0.00	6.27
59	0.00	14.80	0.00	0.00	6.27
60	0.00	0.00	0.00	793.23	6.27
Total	121.50	887.84	2592.00	6361.23	376.14
PV=	120.30	665.22	1980.19	4415.00	281.82

net benefits can be expressed relative to the present value of reduced greenhouse gas (GHG) emissions. This information is provided in Table 19. To make the results more comparable to other similar projects, emission reduction is stated on a CO_2 equivalent basis. Methane is assumed to be 21 more times potent than carbon dioxide. If the entire incremental project costs are allocated to GHG reductions, the result is Y 2,171.84 per ton CO_2 equivalent. A somewhat larger figure results for project revenues. Because the incremental net value of project revenues exceed incremental costs, the result is a positive net benefit per ton CO_2 equivalent reduction. Caution should be exercised in interpreting this per ton benefit. The fact that this is project benefit per ton should be stressed. The benefit per ton in Table 19 could best be viewed as the amount that is left over after paying incremental project costs and adjusting for the time value of money. It is not the benefit from reduced GHG emissions. In this particular example, the project pays handsomely before consideration of global pollution via greenhouse gas emissions. Thus, the cost of GHG emissions reduction is negative.

F. CONCLUSION

23. The ammoniated feed project has been a success—as farmer enthusiasm testifies, and this success is not driven by governmental policies that distort prices. As incomes rise in China the demand for beef is projected to increase more than proportionately. The contribution to global warming from meeting this demand is a concern. With a 38.5 percent reduction of methane emissions per kilogram of live weight

Table 17: ECONOMIC CASH FLOW WITHOUT TREATMENT

Month	Invest	Treatment	Purchase	Revenues	Methane
0	0.00	0.00	518.40	0.00	0.00
1	0.00	0.00	0.00	0.00	5.50
2	0.00	0.00	0.00	0.00	5.50
3	0.00	0.00	0.00	0.00	5.50
4	0.00	0.00	0.00	0.00	5.50
5	0.00	0.00	0.00	0.00	5.50
6	0.00	0.00	0.00	0.00	5.50
7	0.00	0.00	0.00	0.00	5.50
8	0.00	0.00	0.00	0.00	5.50
9	0.00	0.00	0.00	0.00	5.50
10	0.00	0.00	0.00	0.00	5.50
11	0.00	0.00	0.00	0.00	5.50
12	0.00	0.00	0.00	0.00	5.50
13	0.00	0.00	0.00	0.00	5.50
14	0.00	0.00	0.00	0.00	5.50
15	0.00	0.00	0.00	0.00	5.50
16	0.00	0.00	0.00	0.00	5.50
17	0.00	0.00	0.00	0.00	5.50
18	0.00	0.00	0.00	0.00	5.50
19	0.00	0.00	0.00	0.00	5.50
20	0.00	0.00	0.00	0.00	5.50
21	0.00	0.00	0.00	0.00	5.50
22	0.00	0.00	0.00	0.00	5.50
23	0.00	0.00	0.00	0.00	5.50
24	0.00	0.00	0.00	0.00	5.50
25	0.00	0.00	0.00	0.00	5.50
26	0.00	0.00	518.40	1392.00	5.50
27	0.00	0.00	0.00	0.00	5.50
28	0.00	0.00	0.00	0.00	5.50
29	0.00	0.00	0.00	0.00	5.50
30	0.00	0.00	0.00	0.00	5.50
31	0.00	0.00	0.00	0.00	5.50
32	0.00	0.00	0.00	0.00	5.50
33	0.00	0.00	0.00	0.00	5.50
34	0.00	0.00	0.00	0.00	5.50
35	0.00	0.00	0.00	0.00	5.50
36	0.00	0.00	0.00	0.00	5.50
37	0.00	0.00	0.00	0.00	5.50
38	0.00	0.00	0.00	0.00	5.50
39	0.00	0.00	0.00	0.00	5.50
40	0.00	0.00	0.00	0.00	5.50
41	0.00	0.00	0.00	0.00	5.50
42	0.00	0.00	0.00	0.00	5.50
43	0.00	0.00	0.00	0.00	5.50
44	0.00	0.00	0.00	0.00	5.50

cont'd....

Table 17: (cont'd)

Month	Invest	Treatment	Purchase	Revenues	Methane
45	0.00	0.00	0.00	0.00	5.50
46	0.00	0.00	0.00	0.00	5.50
47	0.00	0.00	0.00	0.00	5.50
48	0.00	0.00	0.00	0.00	5.50
49	0.00	0.00	0.00	0.00	5.50
50	0.00	0.00	0.00	0.00	5.50
51	0.00	0.00	0.00	0.00	5.50
52	0.00	0.00	518.40	1392.00	5.50
53	0.00	0.00	0.00	0.00	5.50
54	0.00	0.00	0.00	0.00	5.50
55	0.00	0.00	0.00	0.00	5.50
56	0.00	0.00	0.00	0.00	5.50
57	0.00	0.00	0.00	0.00	5.50
58	0.00	0.00	0.00	0.00	5.50
59	0.00	0.00	0.00	0.00	5.50
60	0.00	0.00	0.00	792.49	5.50
Total	0.00	0.00	1555.20	3576.49	330.28
PV	0.00	0.00	1215.47	2317.45	245.01

Table 19: The Per Ton Cost, Revenue, and Net Benefits of Methane Emissions Reduction Resulting from Use of Ammoniated Straw as Cattle Feed

	Costs per ton CO_2 Equiv. (Y)	Revenues per ton CO_2 Equiv. (Y)	Net Benefit per ton CO_2 Equiv. (Y)	Costs per ton CO_2 Equiv. ($)	Revenues per ton CO_2 Equiv. ($)	Net Benefit per ton CO_2 Equiv. ($)
Economic	(2,171.84)	2,877.36	705.52	($361.97)	$479.56	$117.59

Note: Calculations were made based on present values at a 12% discount rate and the assumption that methane is 21 times more potent as a greenhouse gas than carbon dioxide. Dollar values converted at Y 6 per dollar.

gain, the ammoniated feed project offers a cost-effective method of addressing this concern.

24. The above analysis suggests that the project is extremely viable before any consideration is made of the global environmental benefits. From the viewpoint of greenhouse gases, the ammoniated feed project can be accomplished at a negative cost. But there are three considerations that should be made regarding this project. First,

Table 18: INCREMENTAL ECONOMIC CASH FLOW

Month	Investment	Treatment	Purchase	Revenue	Net benefit	Methane
0	121.50	14.80	0.00	0.00	-136.30	0.00
1	0.00	14.80	0.00	0.00	-14.80	0.76
2	0.00	14.80	0.00	0.00	-14.80	0.76
3	0.00	14.80	0.00	0.00	-14.80	0.76
4	0.00	14.80	0.00	0.00	-14.80	0.76
5	0.00	14.80	0.00	0.00	-14.80	0.76
6	0.00	14.80	0.00	0.00	-14.80	0.76
7	0.00	14.80	0.00	0.00	-14.80	0.76
8	0.00	14.80	0.00	0.00	-14.80	0.76
9	0.00	14.80	0.00	0.00	-14.80	0.76
10	0.00	14.80	0.00	0.00	-14.80	0.76
11	0.00	14.80	0.00	0.00	-14.80	0.76
12	0.00	14.80	0.00	0.00	-14.80	0.76
13	0.00	14.80	0.00	0.00	-14.80	0.76
14	0.00	14.80	518.40	1392.00	858.80	0.76
15	0.00	14.80	0.00	0.00	-14.80	0.76
16	0.00	14.80	0.00	0.00	-14.80	0.76
17	0.00	14.80	0.00	0.00	-14.80	0.76
18	0.00	14.80	0.00	0.00	-14.80	0.76
19	0.00	14.80	0.00	0.00	-14.80	0.76
20	0.00	14.80	0.00	0.00	-14.80	0.76
21	0.00	14.80	0.00	0.00	-14.80	0.76
22	0.00	14.80	0.00	0.00	-14.80	0.76
23	0.00	14.80	0.00	0.00	-14.80	0.76
24	0.00	14.80	0.00	0.00	-14.80	0.76
25	0.00	14.80	0.00	0.00	-14.80	0.76
26	0.00	14.80	-518.40	-1392.00	-888.40	0.76
27	0.00	14.80	0.00	0.00	-14.80	0.76
28	0.00	14.80	518.40	1392.00	858.80	0.76
29	0.00	14.80	0.00	0.00	-14.80	0.76
30	0.00	14.80	0.00	0.00	-14.80	0.76
31	0.00	14.80	0.00	0.00	-14.80	0.76
32	0.00	14.80	0.00	0.00	-14.80	0.76
33	0.00	14.80	0.00	0.00	-14.80	0.76
34	0.00	14.80	0.00	0.00	-14.80	0.76
35	0.00	14.80	0.00	0.00	-14.80	0.76
36	0.00	14.80	0.00	0.00	-14.80	0.76
37	0.00	14.80	0.00	0.00	-14.80	0.76
38	0.00	14.80	0.00	0.00	-14.80	0.76
39	0.00	14.80	0.00	0.00	-14.80	0.76
40	0.00	14.80	0.00	0.00	-14.80	0.76
41	0.00	14.80	0.00	0.00	-14.80	0.76
42	0.00	14.80	518.40	1392.00	858.80	0.76
43	0.00	14.80	0.00	0.00	-14.80	0.76
44	0.00	14.80	0.00	0.00	-14.80	0.76

cont'd....

Table 18: (cont'd)

Month	Investment	Treatment	Purchase	Revenue	Net benefit	Methane
45	0.00	14.80	0.00	0.00	-14.80	0.76
46	0.00	14.80	0.00	0.00	-14.80	0.76
47	0.00	14.80	0.00	0.00	-14.80	0.76
48	0.00	14.80	0.00	0.00	-14.80	0.76
49	0.00	14.80	0.00	0.00	-14.80	0.76
50	0.00	14.80	0.00	0.00	-14.80	0.76
51	0.00	14.80	0.00	0.00	-14.80	0.76
52	0.00	14.80	-518.40	-1392.00	-888.40	0.76
53	0.00	14.80	0.00	0.00	-14.80	0.76
54	0.00	14.80	0.00	0.00	-14.80	0.76
55	0.00	14.80	0.00	0.00	-14.80	0.76
56	0.00	14.80	518.40	1392.00	858.80	0.76
57	0.00	14.80	0.00	0.00	-14.80	0.76
58	0.00	14.80	0.00	0.00	-14.80	0.76
59	0.00	14.80	0.00	0.00	-14.80	0.76
60	0.00	0.00	0.00	0.75	0.75	0.76
Total	121.50	887.84	1036.80	2784.75	738.60	45.82
PV	120.30	665.22	764.72	2053.83	503.59	33.99
IRR					92.27	

increasing the speed at which this new technology is adopted would have desirable effects from a global environmental standpoint. With a current cattle population of 100 million and projections of 169 million by 2010 a tremendous potential exists for expansion of the program. Second, there are periodic shortages of cottonseed cake [6]. The feed supplement is a key ingredient in this process. It provides a source of complete protein, and, as a result, substantially increases the efficiency of feed intake, thereby reducing methane emissions. Ensuring a stable supply or finding suitable alternatives to cottonseed cake is necessary for the success of this methane emissions project. Finally, urea has to be bid away from its more standard agricultural uses. Adequate supply of urea is also a concern that needs to be addressed.

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COEFFICIENTS FOR THE DIFFERENTIAL EQUATION MODEL

COEFFICIENTS

ITEM (x)	"a"	"u"	"A"
Early Rice (10^3 ha)	0.00539167	9,545.01	-1,760,750
Single Cropping Rice (10^3 ha)	-0.015151	12,601.89	844,521.9
Late Rice (10^3 ha)	0.00091755	9,726.04	-1,059,000
Application Amount of Aqua Ammonia (10^3 tons N)	0.106	252.7	-2,181.537
Application amount of nitrogen fertilizer (10^3 tons N)	-0.059818	11,557.63	205,261.9
Rice (10^4 tons)	-0.0116	16,580	1,443,990
Wheat (10^4 tons)	-0.01344	8,451.389	637,4950
Tubers (10^4 tons)	-0.0131	2,590.0	199,823.8
Maize (10^4 tons)	-0.0278	8,274	305,836
Sorghum (10^4 tons)	0.00624	548.74	-87,360
Millet (10^4 tons)	0.01729	467.74	-26,451.66
Other grains (10^4 tons)	-0.01527	1,162.64	77,415.86
Soybean (10^4 tons)	0.0262	1,238.1	-46,135

Note: The above coefficients apply to the general differential equation solution of the form:

$$x=Ae^{-at}+\frac{u}{a}$$

where A = x(0) - b/a = constant

Note: The units of the coefficients have to be derived for each item.