The Impact of Conservation Agriculture on Soil Emissions of Nitrous Oxide

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ABSTRACT

Agricultural activities have greatly changed the global nitrogen (N) cycle and produced nitrogenous gases influencing the environment significantly. Under the Kyoto Protocol (1997), 170 states have agreed to develop and publish national inventories of anthropogenic emissions of several greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

The potential of N_2O emission warming the atmosphere is 290-310 times greater than CO_2, and 10 times greater than CH4. The total annual N_2O emissions are 0.31-0.398Mt in China, 1.19Mt in South-East Asia, and 3.6 Mt in the world. China and India are the highest producers of N_2O emissions in the world.

Research results showed that the N_2O emissions are mainly produced from farmland by denitrification and nitrification processes. In China, the N_2O emissions come from base farmland or unfertilized land (27 per cent), applied chemical N fertilizers (42 per cent), organic manure (23 per cent) crop residues (2 per cent), other N resources (6 per cent). Climate and soil management have influenced the production of N_2O, therefore, selection of reasonable amount of fertilizer with suitable application and improvement of soil management should be a high priority in agriculture to reduce N_2O emission.

Results of experimental research and production practices in China and other countries have shown the advantages of conservation tillage (CT) as it relates to the reduction of soil N_2O emission compared with traditional tillage practices. Some of the key research findings showed the following:

(1) The strong influences of CT system on the reduction of N_2O emission are indirect. Through reduction of wind erosion, the N_2O emission could be reduced from 0.002-0.006 Mt and takes 0.50-1.52 per cent of N_2O emission in China. Through the reduction of water erosion, the N_2O emission could be reduced from 0.00785-0.0102 Mt and takes 1.96-2.56 per cent of N_2O emission in China. The non-burning of crop straw can eliminate 0.0075 Mt of N_2O emission and 0.375Mt of CH_4 emission, resulting in 1.88 per cent of reduction of N_2O emission in China. The reduction of fossil fuel consumption could decrease CO_2 emission to 7.36 Mt.

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2) The direct reduction of N_2O emission from cropland by the change from traditional tillage (TT) to CT system could be expected. The reduction becomes significant after more than ten years

3) Crop productivity and economic benefits to the farmers resulting from the change to CT system has been shown in China which could be a factor in the use of CT system as a main approach to reduce the soil N_2O emission.

1. INTRODUCTION

Agricultural activities have greatly changed the global nitrogen (N) cycle and produced nitrogenous gases significantly influencing the environment. Under the 1997 Kyoto Protocol of the United Nations Framework Convention on Climate Change, 170 nations agreed to develop, periodically update, and publish national inventories of anthropogenic emissions of several greenhouse gases, including CO_2, CH_4, N_2O. A Phase II methodology for producing national inventories of N_2O from agricultural land was proposed by the Intergovernmental Panel on Climate Change (IPCC) in 1997, which assumes a default emission factor of 1.25% of all the nitrogen added to the soil, based on a study by Bouwman (1996). However, this methodology does not account for climate, management practices, irrigation, soil, crop types and other variables that have been found to influence N_2O emissions. [(1)]

The potential of N_2O emission warming the atmosphere is 290-310 times greater than $CO_{2;,}$ 10 times greater than CH_4, and therefore, N_2O is especially concerned in the environmental protection. Farmlands are the main resource of N_2O production in the world and the soil N_2O emission takes 90 per cent of the total N_2O emission from ecosphere to atmosphere. Since 1995, the total N_2O emission produced from farmlands has been estimated at about 0.31-0.398 Mt annually in China, 1.19Mt Nyr^{-1} in the South-East Asia region, and 3.6 Mt Nyr^{-1} in the world. [(2)]

Research results showed that the soil N_2O emission can be produced by denitrification and nitrification. The process of denitrification is influenced by the action of denitrifying bacteria in an anaerobic environment while nitrification is influenced by the action of nitrifying bacteria in an aerobic environment. These microbial processes are strongly influenced by nitrogen fertilizer application. Some papers indicate that more than 30 per cent of the world's total chemical nitrogen was added to Chinese soils in 1990, and more than half of all chemical N fertilizers produced globally are used in crop production of east, south-east and south Asia regions. These areas therefore, count as important regional N_2O source. [(3), (4)]

The emission of N_2O, NO and NH_4 from farmland in South-East Asian countries are estimated and listed in Table 1. From the table, it can be shown that:

(1) The total annual N emission in the region is 1.195Mt and the highest emissions of N_2O, NO and NH_3 occurred in China (0.476Mt) and India (0.416Mt). The N emission value from farmlands in the two countries consists of 75 per cent of the total N emission from farmlands in the region and 23 per cent of the N emission in the world. Both countries have great potential in N emission reduction.

(2) The background emission, consisting of 43 per cent of the total N emission from farmlands in the region shows the importance of soil property on N emission production, whereas, it was only 27 per cent in China.

Table 1. Estimates of emissions of N_2O, NO and NH_3 from croplands in South-East Asian countries (1995) unit: Gg.N

Country	Background*	FSN	FBN	FCR	FAW	Total N emission
China	127.1	202.4	27.7	9.7	109.4	476.3
India	206.8	86.6	23.5	21.8	77.1	415.8
Pakistan	26.3	23.1	0.8	1.1	12.4	63.6
Indonesia	36.8	10.9	3.6	1.4	6.6	59.3
Thailand	24.9	4.5	0.9	0.8	2.6	33.7
Philippines	12.1	3.7	0.1	0.5	2.5	18.8
Bangladesh	9.9	4.2	0.4	0.4	3.6	18.6
Myanmar	12.3	0.4	1.2	0.4	2.4	16.7
Viet Nam	8.2	3.5	0.6	0.4	2.5	15.2
Japan	6.1	4.7	0.3	0.3	2.7	14.2
Others	38.8	11.1	1.3	0.7	11.3	63.3
Total	509.5	355.0	60.4	37.5	233.0	1195.4

The Background, FSN, FBN, FCR, FAW represent background emission, emissions from the use of chemical fertilizers, biological nitrogen, crop residues and animal manure used as fertilizer, respectively.

(3) The contribution of chemical fertilizer usage on N emission was 43% in China, 21 per cent in India, and 30 per cent in the region. This shows that chemical fertilizer application was a major factor for N emission in China.

(4) Animal manure application was the second important contributor for N emission, with 23 per cent in China and 20 per cent in South-East Asia. [4]

2. THE RELATIONSHIP BETWEEN N_2O PRODUCTION AND NITROGENOUS FERTILIZER, ORGANIC MATTER, SOIL MOISTURE, AND CLIMATE

1. The relationship between N_2O production and nitrogenous fertilizer

The application of nitrogenous fertilizers include N chemical fertilizers (urea, NH_4CO_2, $(NH_4)_2P_2O_5$, $(NH_4)NO_3$, etc.) and organic fertilizers (manure, crop stalk and residue, green manure, etc.). The N contents of chemical fertilizer and manure are shown in Tables 2 and 3.

Several decades ago, organic fertilizer was solely used as N nutrition in farmland, but chemical and organic fertilizers both are applied today and chemical N fertilizer as the main fertilizer.

Table 2. N Content in Several Typical of Chemical Fertilizer.

Name of Fertilizer	N Content (%)	P Content (%)
Urea	42-46	/
NH_4NO_3	34	/
$(NH_4)_2P_2O_5$	16-18	46-48
NH_4CO_3	16-17	/

Table 3. N Content in Several Organic Fertilizer (%)..

Name of O.F	Water content	Organic matter	Nitrogen
Pig manure	81.5	15	0.6
Cattle manure	83.3	14.5	0.32
Horse manure	75.8	21	0.58
Sheep manure	65.5	31.4	0.65
Human manure	80.0	little	0.65
Soybean cake	little	little	7.0
Green manure	88.0	15	0.33

The amount of N fertilizer application is directly related with nitrate concentration in soil and production of N_2O emission. Using “Closed Chamber Method” to directly collect soil N_2O emission, the transformed rate of soil N_2O emission from applied

Type of land	Region	Crop	Amount of N fertilizer applied $kg.ha^{-1}$	Rate of NO_2 to N fertilizer
Dry land	Shijiazhuang,Hebei	Maize-Wheat	300	0.54
	Shijiazhuang,Hebei	Maize-Wheat	300	0.70
	Jurong, Jiangsu	Wheat	300	0.32
	Jurong, Jiangsu	Wheat	200	0.19
	Suzhou,Jiangsu	Wheat	180	0.83
	Suzhou,Jiangsu	Wheat	180	0.85
average				0.57
Paddy	Nanjing,Jiangsu	Rice	300	0.16
	Nanjing,Jiangsu	Rice	300	0.38
	Suzhou,Jiangsu	Rice	210	0.22
	Suzhou,Jiangsu	Rice	310	0.19
average				0.24

chemical N fertilizer is shown in Table 4, and the average rate is 0.57 per cent in dry field, 0.24 per cent in paddy field.(4)

The N_2O emission of farmland would not be produced only from chemical fertilizer, but also from manure, crop residue and organic matter, etc. The N_2O emission of farmland has 30 per cent from chemical N fertilizer, 20 per cent from manure, 8 per cent from crop straw and other biological nitrogen sources. The collected N_2O emission from “Closed Chamber” will not be the total N_2O emission into aerosphere from N fertilizers, but actually, part of N fertilizer in top soil is blown away by wind, part of N fertilizer in top soil is flushed away by run-off, and part of N fertilizer in deep soil is eluviated down by rainfall or irrigation. Those N fertilizer will transform to N_2O emission out of farmland and cannot be collected by “Closed Chamber”.

The kind of N fertilizer also influences the transformation producing rate of N_2O emission to total N fertilizer. For example, the producing rate for NH_4 – N, NO_3 – N and Urea fertilizers are 0.01～0.94 per cent, 0.04～0.18 per cent, and 0.15～1.98 per cent, respectively. Chinese farmlands are usually applied with large amount of chemical fertilizer and some of them are easy to be volatilized, such as urea, NH_4CO_3, etc. For instance, 400kg/hm^2 of fertilizer (200kg of Urea, 150kg of NH_4CO_3, 50kg of K) is placed at one crop a year per region of Heilongjiang province (North-East

Table 4. Chemical Fertilizer –induced N_2O rate (%) in Different Area, Land, and Crops.

China); 500～1000kg.ha^{-1}.yr^{-1} (Urea, $(NH_4)_2PO_4$, K) at wheat and maize double cropping area of Hebei province (Center China), 1200～1500kg ha^{-1}.yr^{-1} (Urea, $(NH_4)_2SO_2$, P, k) at rice and wheat double cropping area of Sichuan province (South China).

In 2004, China produced chemical fertilizer 45.19 Mt, among it, N fertilizer 33.04Mt, which is equal to 268 kg/hm^2 of N fertilizer on the average.(7) For reducing the N_2O emission from farmland, it should reduce application amount of N fertilizer and reduce the transform rate for both.

A comparison of N_2O emissions on three treatment fields of no fertilizer applied (CK), chemical N fertilizer applied (CNT) and chemical combined with organic manure applied (CNOT) was made (5) and the results are reflected in Table 5. It shows that N_2O emission was greatly stimulated by chemical N fertilizer application, the N_2O emission directly measured and yearly emission from chemical applied field was 24 times and 26 times than no fertilizer field, respectively. The organic fertilizer also has certain influence; with the N_2O emission directly measured and yearly emission from chemical combined with organic manure applied field was 16 per cent and 17 per cent higher than only chemical fertilizer field, respectively.

The organic manure has a long-term influence on soil N_2O emissions, but the obvious effect of chemical N fertilizer often can be seen within a short period of time (about 3 weeks). Applying the current method on a global scale would result in an estimate of approximately 3.6 TgN_2O-N for global croplands.

Average fluxes of N_2O, NO and NH_3 from croplands in the study area were 2.86, 1.41 and 28.3kg N ha^{-1}y^{-1} respectively. The highest fluxes for each gas occurred

Table 5. Average Emission Rates (1995–1998) and Yearly Emission for Each of the Experiments.

Soil Treatment	Average emission (μg N2O m^{-2} h^{-1})	Yearly emission (kg N_2O–N ha^{-1} y^{-1})
CK	2.2±0.6	0.1±0.001
CNT	52.8±10.6	2.9±0.067
CNOT	61.4±9.4	3.4±0.060

CK - no fertilizer applied, CNT – Chemical N fertilizer applied
CNOT – Chemical N fertilizer and organic fertilizer applied

in China because of the heavy use of chemical N fertilizer (more than 200 kg ha^{-1} yr^{-1}) and the large animal populations there.

India had more cropland area than China, and accordingly had the higher background emission. However, total N_2O and NH_3 emissions from cropland in China were 15 and 75 per cent higher than the corresponding emissions in India.

Uplands had a higher potential for N_2O and NO emissions, whereas rice fields had a higher potential for NH_3 emission; therefore, in Bangladesh and Viet Nam, where rice fields account for a large proportion of the croplands, NH3 emission fluxes were as high as 43 and 38kg N ha^{-1} yr^{-1}, respectively, whereas the N_2O and NO emission fluxes were relatively small.(4)

The default IPCC fertilizer-induced N_2O emission factor of 1.25 per cent was primarily based on the regression analysis of Bouwman (1996). In order to determine the effect of fertilization on N_2O emission in an experiment, unfertilized plot is usually required. From most of the recent reports that have included unfertilized treatments, the fertilizer-induced N_2O emission varied from 1.17 to 12 per cent, with an average of 1.19 per cent. The average fertilizer-induced N_2O emission, for experiments which lasted at least for one year, was 1.31 per cent slightly higher than the average from all measurements. Both values are close to the IPCC default emission factor of 1.25 per cent (4).

On an unfertilized winter wheat field, Rover et al. (1998) measured 0.41kg N_2O-N ha^{-1} in the growing season and 1.43kg N_2O-N ha^{-1} in the following fallow season. Pulses of N_2O emission are often driven by rainfall and thaws (Wagner-Riddle et al., 1997; Dobbie et al., 1999). The results show that the crop could be helpful to reduce the production of N_2O emission and more attention should be paid for the fallow season for N_2O emission production. A suggestion also could be put out that it is necessary, when estimating background N_2O emission, to consider emissions over the entire year, rather than only during a cropping season.

If the chemical fertilizer-induced N_2O emission is 356GgN, 30 per cent of the total emitted N_2O, the animal manure used as fertilizer results 233GgN, and takes 20 per cent of total N_2O emission, which shows a significant influence of organic manure application on N_2O fluxes, and crop residue returned to fields and the cultivation of leguminous crops contributed only have 3–5 per cent influence, respectively, to the total N_2O emission.(4)

The organic N fertilizer and organic P (P_2O_5) fertilizer in China reached 16.4Mt and 7.18 Mt at 1998, respectively, but only 33-70 per cent were utilized as crop nutrition. Other large percentages of organic fertilizer were directed into the atmosphere or river or underground water as immediate pollution resources.

A rough estimation is that a Chinese farmer has used 50 per cent more fertilizer than necessary for many reasons. First is the unreasonable application approach. For example, a Chinese farmer usually uses hand spreading the fertilizer on the soil surface, then using plow or rotary hoe to incorporate it to soil. With this approach, only a small portion of fertilizer can be utilized by the crops. Second is the incorrect quantity of fertilizer. Most of the farmers prefer using more rather than less of fertilizers believing that more fertilizer would have better crops. A report presented the average chemical fertilizer use efficiency is only 30-35 per cent in China. (8)

How to reduce the loss of organic manure and apply the chemical and organic fertilizers in the fields would be big issues for China and Asian countries. To reduce N_2O emission from farmland, the first priority would be improvement of fertilizer application approach. Then, an improvement in the tillage system and irrigation system is suggested.

3. THE RELATIONSHIP BETWEEN N_2O PRODUCTION AND SOIL ORGANIC MATTER

From background emission, it takes 43 per cent of the total N_2O emission from farmland in South-East Asian countries. People understand the importance of soil organic matter on N_2O emission. In general, while soil contains more organic matter (OM), more N_2O emission could be produced, especially the OM decomposing condition is created by tillage.

In China, the background emission only takes 27 per cent of total N_2O emission from farmland which means less organic contents in most of the Chinese farms. Another problem in China is OM in farmland has greatly declined in recent decades, from 4～5 per cent down to 2~3 per cent in North-East region; from 2～2.5 per cent down to 1～1.5 per cent in center region and from 1～1.5 per cent down to less than 1 per cent in north-west region, due to physical turning over or crashing the soil by moldboard plow or rotary hoe, and application of less organic fertilizer.

To meet the food demand, farmers used large amounts of chemical fertilizer and adopted intensive tillage to compensate for the insufficient SOM for high yield. People believed that a large amount of N2O emission has occurred in last decades while the SOM gradually declined. This situation may be the same in most of the developing countries. Therefore, people should take integrative considerations on the SOM. If the lower yield is acceptable, lower SOM certainly produces low N_2O emission; but if higher yields are desired, poor SOM would not be a positive factor to reduce N_2O emission, because fields with poor SOM, requires more N fertilizer and more tillage operations need to be taken for keeping the soil loose. This condition certainly leads to more N2O emission, than SOM release.

A good way to reduce N_2O emission would be to control the decline of SOM and to avoid extra N fertilizer supply when SOM is low while cutting down on extra tillage operations.

4. THE RELATIONSHIP BETWEEN N_2O PRODUCTION AND SOIL MOISTURE, TEMPERATURE, AND WATERLOGGING

It is estimated that 22 per cent of the total N_2O emission produced in China comes from paddy fields and 78 per cent from dry land.

Paddy areas are an important resource of CH_4 emission. The CH_4 emission from paddy is about 60 Gt and takes 10～30 per cent of the total CH_4 resource to the atmosphere. It is not only CH_4 but also the N_2O produced in the paddy field. Both are produced in different conditions.

Research points out that except for fertilizer application, soil moisture and temperature are the main factors influencing N_2O emission during the inundation period when the paddy is full of water and no N_2O emission occurs. In this condition, more CH_4 is produced. Inversely, before paddy dunking and during the beginning of paddy dunking, and drying paddy, large amounts of N_2O is produced as soil moisture drops down. Research also shows that the N_2O formed basically on the aerobic-anaerobic interface during the irrigation and drainage exchange will greatly promote denitrification and nitrification processes which sequentially speeds up the N_2O production, but restrains CH_4 production.(3)

N_2O from paddy fields differ from upland fields in that the soil is generally flooded, a condition unfavorable to nitrification that leads to low N_2O production ratios in denitrification products. The average fertilizer-induced emission factor was 0.26 per cent from paddy fields in the growing season. With an average growing season lasting 117 days, if emission flux in the fallow season were equal to the flux in the growing season, then the annual N_2O emission would be 0.81kg N $ha^{-1}yr^{-1}$. However, many researchers have found that N_2O flux from fertilized paddy fields in the fallow season is higher than N_2O flux in the growing season (Bronson et al., 1997a, b; Tsuruta et al., 1997; Abao et al., 2000), and then background N_2O emission from paddy fields would be comparable to that from uplands. Moreover, paddy fields cannot be completely differentiated from uplands, because some fields are rotated with rice and upland crops in the same year. For the two reasons, the same N_2O emission rate was assigned to both paddy fields and uplands. (10)

For dry land, it produces less CH_4, but produces more N_2O. In natural conditions, soil temperature and moisture are the principal factors which affect N_2O

production. If annual temperature from 7.8^0 C rise to 11.8^0C, N_2O emission increase to 70 per cent; the influence of rainfall on N_2O emission expresses on the peak of N_2O production appear at the second day since rain, after which, the N_2O production tends to be steady.[(3).]

The general understanding is that much more N_2O is emitted from warm and wet soils rather than from cold and dry soils, while nitrogen is not limiting. An exponential relationship could be observed.

5. THE RELATIONSHIP BETWEEN N_2O PRODUCTION AND CLIMATE (TEMPERATURE, RAINFALL PATTERN, AND WATERLOGGING)

The peak period of N_2O emission generally would be in the crop germination period, due to the large amount of N fertilizer placed while seeding. For crop germination, either more rainfall or irrigation should appear in the period. Thus, a study on the effect of climate to N_2O emission would mainly focus on this period.

1) At summer, maize germination season in double cropping region

During the period (June to July), the peak of production of N_2O emission appears, due to a number of reasons: higher temperature at that time, rainfall concentration from June to August in the North of China, water logging always occur when the soil is loosen by moldboard plowing in the traditional tillage system and N fertilizer just placed at seeding time. Chinese farmers have recognized this problem of water logging decades ago, and to avoid damage to young crop seedlings, CT technology was first applied on the summer maize direct planting and they have given up moldboard plowing. Since the adoption of CT technology, a large percentage of the water logging problem has been solved and N_2O emission from cropland was reduced.

2) At spring crops (spring maize, soybean, cereals) germination period in one crop a year region

During April to May, climate is characterized by cold, dry and less rainfall in North of China. It is not always favorable for N_2O emission. Nevertheless, if the soil is too dry for crop growth, the crop should be irrigated, or left to wait for the rainfall. . In this case, N_2O emission could be in a fast production period, especially if the farmer using the irrigation pattern frequently applies water in small amount each time, resulting in the soil's dry and wet exchange condition.

3) At autumn crop (winter wheat in dry land area) germination period

During September to October, moderate temperature, higher soil moisture and less rainfall exist. Due to suitable crop germination conditions with less rainfall, there would be least production of N_2O emission during all germination seasons.

4) At winter crop (winter wheat, ripe seeds) germination period in rice-wheat double cropping area of south China

During October to November, the rice paddy is drained out of flood water and gradually changes to dry land, but soil moisture is still high enough for crop growth. The temperature is moderate above 100C, and this environment of moisture change is also favorable for production of N_2O emission.

5) At rice seedling growing period

Due to water flooding, the soil pores are filled and a few O2 is available. With this condition, N_2O emission could be produced.

The effects of irrigation, cropping (fallow, barley with grass) and N fertilization (unfertilized, 103 kg N ha) on the composition of soil, air, and direct N_2O emission from the soil (using the closed chamber method) in loamy clay soil experiment field was studied in 1993. The measurements were made weekly during the growing season and three times after harvesting. The composition of the soil air did not indicate severe anoxia in any treatment or combination of treatments, but the accumulation of N_2O in the soil air indicated that hypoxia was common. At the start of the irrigation, the emissions were small, even though there was much ammonium and nitrate in the soil. Larger emissions occurred later. The largest emissions were found when 60-90 per cent of the soil pore space was filled with water. Irrigation and fertilization with N both roughly doubled the cumulative N_2O emission. Most N_2O was lost from the irrigated fertilized soil under fallow (3.5 kg N ha^{-1}), and least from the non-irrigated unfertilized soil under barley (0.1 kg N ha^{-1}).[6]

6. HOW N_2O PRODUCTION IS INFLUENCED BY A CHANGE FROM TT TO CT

TT (traditional tillage), CT (conservation tillage), CA (conservation agriculture) currently is called CT for the reason of concentration on the tillage change in China and other developing countries such as India and Pakistan.

Many experimental researches and production practices in China and other countries have shown the follow advantages of CT related to the reduction of soil N_2O emission:

1) Reduction in soil wind erosion
2) Reduction in soil water erosion
3) Avoidance in burning crop residue

4) Avoidance of water logging
5) Enrichment of soil fertility
6) Reduction in fossil fuel consumption

1. Reduce soil wind erosion to cut down the loss of soil N fertilizer as well as N_2O emission

China has a serious soil erosion problem, with a total erosion area of about 3.28Mkm^2 and takes 34.2 per cent of the total continent area, with 5 Gt (Billion tones) of soil losses each year, of which 3.3 Gt comes from farmlands.

Wind erosion area is approximately 1.6 Mkm^2 and about 12～14 Mhm^2 is mainly farmland located in North and West of China. The wind erosion losses from different measures are shown in Table 6. Soil erosion losses are about 10～80 t/hm^2.y in general, and farmland concentrated on 10～20 t/hm^2.y, which is equivalent to 1～1.5 mm top soil blown away. For the soil loss, moldboard plowing has great contribution to bring the fine particles in bottom soil to the surface, thus erosion can be continue, otherwise, erosion should be gradually attenuated while surface fine particles exhausted.(11)

Soil wind erosion causes dust storm problems, polluted environment, some of soil fine particles, like PM10, are brought up to the sky and blown thousand of miles away. The situation influences transportation, industrial production, and peoples' lives. Many useful soil fertilizers, e.g., OM, N, P, K, are concentrated in the "blown out dust" which may sink in the city, sea or mountain areas. Only a few of soil N fertilizer blown out is absorbed by vegetation while most of it would finally go into the atmosphere as N_2O or other N emission.

With CT, moldboard plow operation is avoided and crop residues protect the soil. As a result, soil and wind erosion can be significantly reduced.

The China Agricultural University measured the nutrition in the top soil and "wind collection". It is the dust from soil and collected by dust sampler in Hebei province and Inner Mongolia and the results are shown in Table 7. The amounts of soil erosion by wind in experimental fields of traditional tillage and conservation tillage are shown in Table 8.

The "wind collection" contained 1.24～2.32 times higher OM and 1.36～1.74 times of N fertilizer than top soil, respectively, as shown in Table 7. Taking the soil wind erosion 10～20 t/hm^2, with the 3 per cent of OM content in the wind collection, a 300～600 kg/hm^2 of OM loss from wind erosion can be estimated and with 0.17 per cent of full N content in wind collection, a 17～34 kg/hm^2 of full N loss from wind erosion can be estimated.(12) The reduction of wind erosion from a change of TT to CT system is 41～76 per cent with 60 per cent on average as shown in Table 8. Thereupon, the change of TT to CT system can reduce 10.2～20.4 kg/hm^2 of full N loss. The wind eroded farmland is estimated at 10～15Mhm^2 in China, thus, the change from TT to CT system can reduce 0.102～0.306Mt of N fertilizer loss.(13) Consider the atomic weight of nitrogen is 14 and oxygen 16, then, 1 kg of nitrogen is converted to (14+14+16)/(14+14) = 1.57kg of N_2O emission.

Table 6. Soil Wind Erosion Losses Measured in Different Region and Climate.

Place and Time		Soil OM	Total N	Total P	Total K	Method of measurement
Fengnin, Hebei 2002	Top soil (5cm)	1.3	0.096	0.014	1.83	Field sampler
	Wind collection	3.016	0.167	0.038	1.99	
	Concentrate rate	2.32	1.74	2.70	1.09	
Zhenlan Banner Inner Mongolia 2003	Top soil (5cm)	1.38	0.103	0.016	1.82	Portable wind tunnel
	Wind collection	3.01	0.179	0.038	1.96	
	Concentrate rate	2.18	1.74	2.38	1.08	

The percentage of N fertilizer in the dust could be transformed to N_2O emission. Assuming that it is the same with the IPCC default emission factor of 1.25 per cent of all N fertilizers added to the soil, then, the change from TT to CT system can reduce 2000~6000 t of N_2O emission through reduction of wind erosion:

0.102～0.306Mt * 1.57 *1.25% = 0.002～0.006Mt

Table 7. The Nutrition Contents in Top Soil and “Wind Collection” Unit: %

Table 8. The Comparison of Soil Wind Erosion from TT and CT Fields.

No	Place of measure	Soil type	Amount of wind erosion			Method of measure	Time of measure
			TT	CT	Reduce Rate (%)		
1	Fengnin,Hebei	Sand soil	11.7	2.81	76	Field sampler	2002
2	Zhangbei, Hebei	Sand soil	10.6	3.6	66	Field sampler	2002
3	Zhenglan Banner, Inner Mongolia	Sand soil	5.7	3.37	41	Field sampler	2003

2. Reduce soil water erosion to decrease the loss of soil N fertilizer as well as N_2O emission

The Northern-East part of China and Yellow River drainage area are main water erosion regions in the country. By water erosion, 200～300 Mt of top soil loss in North-East China and 1600 Mt of soil loss in Gansu, Ningxia Shaanxi, Shanxi etc. of Yellow River drainage area each year are estimated.

No	Region	Climate	Type of soil	Amount of W.E (t/hm^2)	Method of measure	Mea-sure time
1	Farmland, Beijing	Semi-Humid	Loam	11.28	Set pole	2005
2	Farmland, Shanxi	Semi-Humid	Loess	13.7	Set Pole	1990
3	Farmland, Sandong	Semi- Humid	Sand-loam	21	Set pole	1992
4	Farmland, Shaanxi	Semi-Humid	Loess	18.9	Modeling	1998
5	Sand, Hebei	Semi-arid	Sandy	96	Set pole	2002
6	Sand, Inner Mongolia	Semi-arid	Windy sand	80	Set pole	1993
7	Farmland, Inner Mongolia	Semi-arid	Sand soil	21.6	Trap collection	2002
8	Farm/Grassland, Qinghai	Arid	Sand soil	7.5～43	Cs-137 label	2000
9	Farm/Grassland, Xinjiang	Arid	Sand soil	31-60	Cs-137 label	1998

A report showed that 456 Mt of soil was flushed into the Yellow River and Hai River from Shanxi province, contains 5.08 Mt organic matters and 0.3 Mt N and P fertilizers, which is equal to 25 per cent of the chemical fertilizers used in the whole province. Using Shanxi figures, the province has a total land area of 300,000 Km^2. The average water erosion rate is 1520 t/km^2 and 15 t/hm^2; regardless it is farmland or non-farmland. However, the N and P fertilizer losses mainly from farmland is 400 Mhm^2 in Shanxi province, thus, 75 kg/hm^2 of N and P fertilizer loss can be calculated which matches with the 25 per cent of the 300 kg/hm^2 chemical fertilizer application in the province.

For a 4t/hm^2 yield of wheat, typically 120kg of pure N is applied and 60 kg of $P(P_2O_5)$ or 192kg of urea and 108kg of $(NH_4)_2P_2O_5$, thus, loss of 50kg of pure N per hectare from water erosion can be estimated.

The soil water erosion is strongly influenced by land slope, amount of rainfall and rain stress. For example, when the land slope from 5 per cent changes to 15 per cent, the water erosion would be increased 10 times (measured by Shanxi Agricultural University). Another example showed the great influence of rainfall stress on the amount of water erosion. The China Agricultural University measured the water erosion in 1998 was 1.72 t/hm^2, but it increased to 73.65 t/hm^2 with annual rainfall 421mm in 1999. This amount was 40 times more than in 1998. The main reason was the fact that in 1999, the annual rainfall of 421mm was higher than the 339 mm in 1998, especially when there were twice of the 40 more mm strong storms in 1999, while no strong storm happened in 1998.

Soil water erosion can be significantly reduced from CT system. A comparison between TT and CT on different slope land is shown in Table 9. From the table, CT can reduce water erosion by 80 per cent on 4～5 per cent slope field which are typical dryland situation. If the 80 per cent reduction of water erosion by TT is changed to CT system, CT would reduce about 40kg/hm^2 of pure N loss in the Yellow River drainage provinces. This middle grade water erosion (1500t/hm^2) area has approximately 10～13 Mhm^2 in the Yellow River and Huai River basin, thus, the total reduction of 0.32～0.4Mt pure N loss can be calculated from water erosion.

Regardless, the transform rate of N_2O emission for water eroded N fertilizer should be larger than wind erosion due to the anaerobic environment available. However, for reliable consideration, the same transform rate of 1.25 per cent is still employed here for calculation. The total reduction of N_2O emission from water erosion reduced in the Yellow River basin ranges from 7850 to 10200t.

$$40Kg/hm^2 * 1.57 * 1.25\% * 10 \sim 13\ Mhm^2 = 0.00785 \sim 0.0102\ Mt$$

Leaching problem and nitrogen fertilizer leaching would greatly increase N_2O emission production. However, this largest component of indirect agricultural N_2O emission is not yet well defined.

The current IPCC default value for the proportion of leached N emitted as N_2O emission is 2.5 per cent (IPCC, 1996), which represents the sum of N_2O emissions resulting from N leaching in groundwater and drainage ditches, rivers and estuaries. It has been approved that the change from TT to CT system would reduce soil water erosion and reduce N fertilizer in the drainage ditches, rivers and estuaries, but the amount of fertilizer losses reduced from leaching is still not clear. (14)

Table 9. The Comparison of Water Erosion from TT & CT on Different Slope Lands.

No.	Place of measure	Land slope	Amount of water erosion			Method of measure	Time of measure
			TT	CT	Reduce Rate (%)		
1	Shouyang, Shanxi	4%	1.72 (t/hm^2)	0.46 (t/hm^2)	73	Tipping bucket	1998 (no storm)
2	Shouyang, Shanxi	4%	73.65 (t/hm^2)	14.5 (t/hm^2)	80	Tipping bucket	1999 (had storm)
3	Shixian, Shanxi	5%	0.454 (g/s)	0.048 (g/s)	88	Simulation rainfall on artificial slope lands	1999
		10%	3.327	1.154	65		
		15%	6.046	3.543	41		

2. Avoid burning crop residues

About 600Mt of crop stalks are produced each year in China and these contain 3Mt of N, 0.7 Mt of P, 7 Mt of K fertilizers, besides the large percentage of organic matter in the stalks. In traditional tillage system, farmers usually burn or discard crop straws or stalks to make field ready for seeding. For the farmers, stalk burning would be a cheaper, quicker, and easier way but it will produce smoke, directly polluting the aerosphere and creating hazards to people and transportation

To stop burning crop residues, which has great contribution to greenhouse gas (includes N emission), there are several ways which farmers can do, e.g., incorporating the straw into the soil or transporting straw out of the field; making manure, etc. While the straw has no other use for the farmers, the crop straw and residues can be left on the soil surface by implementing a CT system. This system is cheaper and easier for the farmers to handle.

In China, the local government officers support the CT, as it can stop crop residue burning compared to other methods. Currently about 25 per cent of crop residues is burned in China producing 0.0075Mt of N_2O emission and 0.379Mt of CH_4 emission but less of CO_2 emission. If through adoption of CT system, these great amounts of emission could be eliminated.

4. Avoid water logging in summer season

In the double cropping region of North China, the summer maize is planted during the middle of June, which is usually the start of the rainy season. Thus, a big problem which bothers farmers is the mortality of the maize seedlings due to water logging in TT system. Another problem is the N_2O emission from the soil to the atmosphere. Although there are no scientific figures to support this point of view, it can be deduced that there must be a peak period for the production of N_2O emission, where there is higher temperature at maize seedling growth period and large amount of N fertilizer were applied into the soil a few days earlier. With the rainfall concentration, water logging is expected.

CT changed the tillage pattern, firstly through the direct seeding made during the planting time one week earlier than in the TT system. Thus, when the rains come, the seedling is stronger while the N fertilizer has been placed after a longer time. Secondly, the soil is not loosen by non plowing of the field and less water logging. CT helps solve the seedling mortality problem, and reduces N2O emission.

5. Rich soil fertility

When a farm changes from TT to CT system, common soil gradually becomes rich due to the returning of crop stalks into the field and the halting of moldboard plowing and rotary hoeing. The soil would then have higher OM and N, P, K nutrition; more soil aggregates of water stability and more soil organisms.

For example, a 15-year wheat CT trial plots in Linfen of Shanxi province, after adoption of CT system in 1992, resulted in an increase of SOM from 0.89 per cent to 1.30 per cent in 13 years, with each year having an increase of 0.031 per cent; the full N and fast N increased by 1.2 per cent; the soil aggregates of stability was more than 32～53 per cent than TT field at the end of 12 years; the earthworms from 0 in 1992 to 3～5 heads/m^2) in 1996, and 15～20 heads/m^2 in 2002.(5)

The change in the soil conditions would be useful to reduce chemical fertilizer usage under the same yield, while cutting down N_2O emission; release soil compaction by more aggregates; reduce water logging; increasing SOM and N, P, K fertilizers contents in turn resulting in soil fertility by less OM oxidation then escaping into atmosphere, and less soil organisms killed. The negative effects are the increase of soil bulk density and decrease of soil porosity rate, but they are still in the allowable range.

6. Reduce fossil fuel consumption

With the TT system, there are many field machine operations with large amounts of fossil fuel requirements. Take the field machine operations in wheat and maize double cropping area of Hebei province as an example. There are a total of eight machine operations in the summer season for harvesting wheat and planting maize, with a fuel consumption of 79.5 kg.ha^{-1}. During the fall season, there are nine operations for harvesting maize and seeding wheat with fuel consumption of 94.5 kg.ha^{-1}(Table 10). The manual operations include hand picking of the maize ears, hand thinning of the maize seedlings, hand weeding, etc., while others are not taken into account.

CT can largely reduce field operations mainly by cutting down on tillage operations and transportation-related work (moving crop stalks out of the field and transporting organic manure). In the summer season, the eight operations were reduced to six with fuel consumption down to 54 kg.ha^{-1}. There was also a big reduction of operations during the fall season, e.g., from 9 down to five with fuel consumption of 42 kg.ha^{-1} (Table 11).

The change from TT system to CT system can cut down six operations (35 per cent reduction) and saving fuel 78 kg.ha^{-1} (45 per cent reduction) annually.

From the current tillage systems and implements used in China such as moldboard plow, rotary hoe, chisel plow, heavy disc harrow, rotation tillage (one year moldboard plow, one year rotary hoe, another year disc harrow, etc.,) ridge tillage and conservation tillage, most of the reduction in operations and savings in fuel is in the CT system.

Table10. Operation, Machine and Fuel Consumption of TT System in a Double Cropping Area of Hebei Province.

If 70 per cent of the cropland in North of China can adopt CT, the total fossil fuel savings could be 2.3Mt each year.

Double cropping area 16Mha* 0.7 * 78 kg.ha^{-1} = 1.25 Mt fuel saved

Fossil fuel reduction represents the greenhouse gas (CO_2 and other emissions) reduction from the engine of farm machinery; the gas value is estimated to be about 3.2 kg CO2 per kg of fuel. [15]

If 70 per cent of the cropland in North of China can adopt CT, then the reduction of GHG could reach 7.36Mt.

GHG reduction in North China 2.3Mt * 3.2 = 7.36 Mt CO_2 emission

Table 11. Operation, Machine & Fuel consumption of CT system in double cropping area of Hebei province

No.	Summer season			Fall season		
	Name of operation	Machine used	Fuel Consumption (kg.ha^{-1})	Name of operation	Machine used	Fuel Consumption (kg.ha^{-1})
1	Wheat Harvesting	Combine Harvester	27.0	Transport* Maize ears	Trailer	12.0
2	Transport Wheat	Trailer	9.0	Chopping Maize stalk	Chopper	12.0
3	Sub-soiling (once 3 years)	Chisel plow	6.0**	No-till planting Wheat with fertilizing	No-till Wheat Seeder	12.0
4	Direct Planting maize	No-till planter	6.0	Spray Herbicides	Sprayer	3.0
5	Spray Herbicides	Sprayer	3.0	Transport Seed, Fertilizer	Trailer	3.0
6	Transport Seed, Fertilizer	Trailer	3.0		Subtotal	42.0
7		Subtotal	54.0			

No.	Summer season			Fall season		
	Name of operation	Machine used	Fuel Consumption (kg/hm^2)	Name of operation	Machine used	Fuel Consumption (kg/hm^2)
1	Wheat Harvesting	Combine Harvester	27.0	Transport Maize ears	Trailer	12.0
2	Transport Wheat	Trailer	9.0	Transport Maize stalk	Trailer	15.0
3	Disc Cutting	Hr.Disc Harrow	9.0	Transport Manure	Trailer	18.0
4	Plowing	Moldboard Plough	16.5	Stalk cutting	Hr. Disc Harrow	10.5
5	Harrowing & leveling	Light Harrow	6.0	Deep Plowing	Moldboard Plough	18.0
6	Maize planting	Maize Planter	4.5	Disc Harrowing	Light Harrow	6.0
7	Rolling	Roller	4.5	Making ridge leveling Land	Ridge maker	6.0
8	Transport Seed Fertilizer	Trailer	3.0	Wheat seeding	Wheat drill	6.0
9		Subtotal	79.5	Transport Seed Fertilizer	Trailer	3.0
					subtotal	94.5

A paper presented an idea that the CT system can offset GHG emissions (CO_2., N_2O, and CH_4). Yet, it only shows the significance in longer-term adoption of 10 years in humid climates and 20 years in humid and dry areas (Table 12). [16] The author agrees with the idea when it directly measures GHG emission (includes N_2O emission) from cropland. People may not find a big difference in TT and CT fields unless they have adopted CT for a long time. Thus, the less N_2O emission can be expected in CT fields.

The influences of CT system to the N_2O emission from cropland can be concluded as follow:

1) The strong influences of CT system on the reduction of N_2O emission are indirect: through reduction of wind erosion, the N_2O emission could be reduced 0.002～0.006Mt and takes 0.50～1.52 per cent of N_2O emission in China; through reduction of water erosion, the N_2O emission could be reduced at 0.00785～0.0102Mt and takes 1.96～2.56 per cent of N_2O emission in the whole country.

Avoiding to burn straw can eliminate 0.0075 Mt of N_2O emission and 0.375Mt of CH_4 emission, which has another 1.88 per cent reduction of N_2O emission. Reduction of fossil fuel consumption can decrease 7.36 Mt of CO_2 equivalent emissions.

2) Direct reduction of N_2O emission from cropland by the change from TT to CT system could be expected, yet becomes significant after a longer period of time, e.g., 10 or more years.

3) The crop production and economical benefits of farmers changing to the CT system from TT system has been clearly shown. This change would be a great factor in the selection of CT system as a main approach to reduce the soil N_2O emission.

Table 12. The Differences of Soil-derived GHG Fluxes and GWP (global warming potential)
After Different Years TT Change to CT System Unit: (kg $ha^{-1}y^{-1}$)

	Year 5	Year 10	Year 20

	fluxes	GWP	fluxes	GWP	fluxes	GWP
	Estimate	Estimate	Estimate	Estimate	Estimate	Estimate
Soil organic C						
Humid	194	710	213	-780	222	-815
Dry	306	1123	-37	137	97	-356
N_2O						
Humid	3.8	1114	1.1	330	4.2	-1238
Dry	1.3	398	0.9	268	0.0	8
CH_4						
Humid	0.6	13	0.6	-13	0.6	-13
Dry	0.6	13	0.6	-13	0.6	-13
Soil-derived GWP						
Humid		391		-463		-2066
Dry		1508		392		-361

GWP units are CO_2 equivalents (kg ha^{-1} y^{-1}). Values in the columns headed by year 5, 10 and 20 are estimates for 5, 10 and 20 years after conversion from conventional tillage to no-tillage. Negative numbers indicate a reduction in global warming potential or a mitigation of global warming.

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