The Impacts of Conservation Tillage on Atmosphere Warming, Dust Storm, and Soil Deterioration in North China

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ABSTRACT

The increasing population, diminishing resources, and environmental deterioration are great challenges to humankind. In China, the problems related to the fragile environment, population increase, drought, dust storm, and soil deterioration have limited the socio- economic development and improvement in human living conditions.

Many researches and practices in North China and the world have approved of conservation tillage (CT), aside from its benefits of yield increases and costs reduction, including the social benefits of depressing wind erosion, greenhouse gas emission, and improving soil fertility. Due to the profitability resulting from the use of CT, government planning and support from all sectors is necessary.

Key words: Conservation tillage, environment protection, resource savings

1. DEPRESS DUST STORM

Dust storm has been a big environment problem in North China, which occurred five times in the 1950s; six times in 1960s; 13 times during the 1970s; 14 times in the 1980s and 23 times during the 1990s. Dust storms resulted in soil desertification and directly influenced people's lives.

Most soil dusts have large particles rolling or jumping forward from the ground. These particles could damage crops and fields. The fine particles can be suspended in the sky and move thousands of miles away, usually in the diameter of less than 10 µm (PM_{10}) motes, gain entry into the human lungs, and harm human health. The amount of mote is a major monitoring index in atmosphere environment control. The PM_{10} mainly comes from crop lands.

The China Agricultural University (CAU) measured PM10 production from different soil surfaces under the wind speed of 12 m/s (Table 1).

Table 1. Measured PM_{10} amount (unit: g)

Soil Surface	Growth weight	Paper weight	PM_{10} weight
Plow field	2.65	2.4386	0.2114
Short stubble	2.5633	2.4386	0.1247

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Chopped stalk	2.5037	2.4386	0.0651
High stubble + Chopped stalk	2.4862	2.4386	0.0476

A rule for the total amount of PM_{10} production is: Plow field > short stubble cover > chopped stalk cover > chopped stalk plus high stubble cover. Compared to the plowed field, short stubble cover has 41 per cent less mote; chopped stalk cover (all stalk left in field) has 69.21 per cent less chopped stalk; and high stubble cover (all stalk left in field) has 77.48 per cent less of PM_{10} produced.

PM_{10} mote is only a small percentage in wind erosion. For example, the average in Beijing is 1.4 per cent, but in a large area, the whole amount of PM_{10} can be quite large. All croplands plowed in Beijing could produce 84,000 tones of PM_{10} annually. Each person in Beijing would share 7 kg of PM_{10} mote. Adoption of CT can efficiently reduce soil dust and $PM_{10.}$ If the whole of Beijing would adopt CT with 6t/hm^2 residue cover， PM_{10} could be reduced to 19,000 t only.

2. CT REDUCES GREENHOUSE GASES

GHG (green house gases) are mainly CO_2, CH_4 and N_2O, and their contributions to atmosphere warming in the world are 60 per cent, 20 per cent, and 6 per cent, respectively.

China is a big producer of GHG. It produces 13 per cent CO_2 and 10 per cent N_2O in the world. A large percentage of N2O and CO_2 come from agriculture, therefore, it is very important to reduce N_2O and CO_2 emissions through CT.

2.1 Reduce CO_2

CO_2 comes from burning coal, fossil oil, plant biomass, and escaping of soil carbon. Traditional mechanized agriculture did produce CO_2 into the atmosphere, through burning stalk, burning fuel in machine operation, manufacture of chemical fertilizers, herbicide and machinery, as well soil carbon escaping during moldboard plowing.

The adoption of CT could stop burning of stalk, reduce fuel consumption and cut down C escaping from the soil.

CT can largely cut down tillage and transportation operations, e.g., moving crop stalks out of the field and transporting organic manure into field. With the adoption of CT, a savings of 30 kg/hm^2 of fuel or 40 per cent of fuel consumption in one crop a year region and 78 kg/hm^2 of fuel in double cropping region in Northern China could be expected.

With CT adopted on 70 per cent of cropland, the total fossil fuel savings could be

1.924Mt each year.

One crop a year area 50M hm^2 * 0.7 * 30 kg/hm^2 = 1.05 Mt fuel saved
Double cropping area 16M hm^2* 0.7 * 78 kg/hm^2= 0.873 Mt fuel saved

Fossil fuel reduction represents the GHG reduction from the engine of the farm machinery, with the estimated gas of 3.2 kg of CO_2 or 0.01kg of N_2O for 1 kg of fuel burning.(1)

Assuming that fossil fuel produce 70 per cent CO_2 and 30 per cent N2O emission, the CO_2 emission could be produced at 93.3 kg/hm^2 and 4.31Mt in NC.

$$1.924Mt * 0.7 * 3.2 = 4.31Mt$$

Observations from US, Canada, and China have shown that traditional tillage (moldboard plow) loses soil organic matter (SOM), and increased CO_2 emission into the atmosphere. Reversely, OM increased in soil and CO_2 decreased in the atmosphere during the CT period. Taking an average figure from Northern China that no-tillage can increase SOM by 0.01 per cent per year, CT could store 240$kg/hm^2$of C in the soil, or reduce 878kg/hm^2 of CO_2 emission into the atmosphere. While 70 per cent of Northern China cropland adopted CT, the direct CO_2 emission reduction is 45Mt from reducing fuel consumption and soil C escaping, which is about 1.2 per cent of total CO_2 emission in China.

$$66Mhm^2 *0.7*(93.3 + 878)\ kg/hm^2 = 44.9Mt$$

It is clear that CT can reduce CO_2 emission and mainly store more C in the soil. At the same time, the stored C in the soil would be more useful to improve soil fertility, structure, and water infiltration; increase ground water and reduce soil compaction. Many scientists believe that the contribution of CT in soil C storage would not be less than one crop production, thus, should be supported by the government.

2.2 Reduce N_2O

The potential of N_2O emission warming atmosphere is 290-310 times greater than CO_2, and 10 times greater than CH_4. Therefore, there is a grave concern by China for the environment.

The total annual N_2O emissions are 3.6 Mt in the world and 0.31-0.398 Mt in China. About 90 per cent of N_2O emissions come from farm lands, 75 per cent of which come from dry land and 25 per cent from paddy field.

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

(1) Reduce soil wind erosion;
(2) Reduce soil water erosion;
(3) Avoid burning crop residue;
(4) Reduce fossil fuel consumption;

(5) Improve soil structure;
(6) Improve soil fertility

2.2.1 Reduce Soil Wind Erosion

China has a serious problem on soil erosion. Wind erosion area is about 1.6 Mkm^2 and about 12-14 Mhm^2 is farm land mainly located in North and West of China. The wind erosion losses in farm land are 10-20 t/hm^2 and the "wind collection" has contained 1.2-2.3 times higher of OM and 1.3-1.7 times of N fertilizer than top soil, respectively (Table 2).

Table 2. The Nutrition Contents in Top Soil and "Wind Collection".

(Unit: per cent)

Place and time		Soil OM	Total N	Total P	Total K	Method of measure-ment
Fengnin county, 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	

12-14 Mhm^2 * 10.2-20.4 kg/hm^2* 1.57 *1.25 per cent = 2001-6024t

Note: Considering that the atomic weight of nitrogen is 14 and oxygen 16,
1 kg of N is converted to (14+14+16)/ (14+14) = 1.57 kg of N_2O emission.

Taking the soil wind erosion 10-20 t/hm^2, 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. The reduction of wind erosion from TT to CT system is 60 per cent on the average, while the change of TT to CT can reduce 10.2-20.4 kg/hm^2 of full N loss. Employing the IPCC default factor that 1.25 per cent of applied N fertilizer can be transformed to N_2O emission, then, all the wind area changes the tillage system from TT to CT and can reduce to 6024 t of N_2O emission through reduction of wind erosion.

2.2.2 Reduce Soil Water Erosion

The average water erosion in Shanxi province is about 15 t/hm^2. In an eroded soil, there is about 50kg/hm^2 of full N and 25kg/hm^2 of full P fertilizer.

Soil water erosion could be reduced to 80 per cent on 4-5 per cent slope field by adopting the CT system. Such a slope is typical in the Yellow River basin. Given an 80 per cent water erosion reduction, CT would reduce about 40kg/hm^2 of full N loss in 10-13 Mhm^2. Thus, a total reduction of 0.32-0.4Mt full N loss can be calculated from water erosion. Using the same transformation rate of 1.25 per cent of N_2O emission to N fertilizer, the total reduction of N_2O emission from water erosion reduced in Yellow River basin is between 7850-10200 t.

$$40Kg/\ hm^2 * 1.57 * 1.25\% * 10\text{-}13\ Mhm^2 = 7850\text{-}10200t$$

2.2.3 Avoid Burning Crop Residue

Approximately 600Mt of crop stalks are produced each year in China which contains 3Mt of N, 0.7 Mt of P, 7 Mt of K fertilizers. Currently, 25 per cent of crop residue is burned in China which produces 0.0094Mt of N_2O emission, 0.379Mt of CH_4 emission, and less of CO_2 emission.

With the adoption of CT system, 10 per cent of crop stalks burning could be prevented, thus, 3750t of N_2O emission and 151,000t of CH_4 emission could be eliminated.

2.2.4 Reduce Fossil Fuel Consumption

CT can cut down fuel consumption by 41.6kg/hm^2 in NC, compared to TT system. With CT adopted on 70 per cent of crop land in north of China, the total fossil fuel savings could be 1.924Mt each year.

Assuming that 30 per cent of fossil fuel emission is N_2O emission, about 5772t of N_2O emission could be reduced.

1.924Mt * 0.01* 0.3 = 5772t of N_2O emission

Analysis has shown that there are immediate and indirect influences with the reduction of 12851-24996t N_2O emission or 3.6-7.1 per cent of whole N_2O emission in China.

Direct influence shows that N_2O emission change can be measured directly from cropland using the "close chamber method". However, there are no scientific figures to show the influence clearly at the moment.

From the positive side, the improvement of soil fertility and structure would be useful to reduce the amount of N fertilizer application, as well as the reduction of N_2O emission. However, the rich soil base would produce more N_2O emission itself. Some research mentioned that the frequent exchange of soil dry and wet conditions would induce N_2O emission production; soil water logging easily creates an anaerobic environment, producing more N_2O emission. The situation is rather complex and uncertain.

Dr. Johan Six of the California University, USA, concluded that the CT system can directly offset GHG emissions (CO_2, N_2O, and CH_4), only in longer-term adoption, e.g., ten years adoption of CT system in paddy fields (humid area); the fluxes global warming potential (GWP) becomes negative, implying a reduction of GHG. Adoption of CT for 20 years in paddy and dry land areas both show negative GWP fluxes while in a short-term application of CT, the GHG may be less, may be more.

3. CT IMPROVES SOIL PRODUCTIVITY

Soil productivity has been declining in most of the croplands in Northern China which has been showing a reduction of soil organic matter from 4-5 percent to 2-3 per cent in the North-East area; 1-2 per cent reduction in Central China. Further, many croplands lose productivity by desertification and desolation. Soil deterioration has become a major factor that limits crop production capability in China. The reasons of soil productivity reduction are soil erosion and over utilization.

China's soil erosion problem has reached 5 Bt annually, out of which 3.3Bt come from crop lands. From this amount, an equivalent of 2.5 mm top soil is lost each year. Wind erosion is a major problem in North-West China while water erosion is the major problem in loess tableland and North-East China.

3.1 Wind Erosion

Since the 1990s, Chinese researchers on water and soil conservation have done measurements on wind erosion. Research show that wind erosion is between 10-80 t/hm^2 and cropland concentrated in 10-20 t/hm^2 (Table 3).

Table 3. Wind Erosion Results in North of China.

No	Land type/region	Climate	Soil type l	Amount of W.E (t/hm^2)	Method of measure-ment	Mea-sure-ment 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/Shand-ong	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 and grass land/ Qinghai	Arid	Sand soil	7.5-43	Cs-137 Label	2000
9	Farm and Grass-land/ Xinjiang	Arid	Soil	31-60	Cs-137 Label	1998

Soil nutrition in wind dust is higher than in the top soil. CAU has measured the top soil and wind collection materials in Hebei and Inner Mongolia, results of which are shown in Table 2.

Take the wind dust of 10-20t/hm2 which contains 2-3 per cent of OM and 0.17 per cent of full N. Here, the soil nutrition loss by wind erosion is 200-600 kg/hm^2 of OM and 17-34 kg/hm2 of full N, resulting in a decrease of SOM content of 0.008-0.025 per cent annually.

Without using a moldboard plow, soil fine articles would gradually be depressed in the top soil and wind erosion intensity would be reduced. With a moldboard plow, bottom soil is turned up, new fine particles are made available, and soil erosion continues. If mouldboard plowing continues for 100 years and soil fallow is in bare condition, wind erosion would result in SOM depression of 0.4-1.25 per cent. This situation would turn rich soils to poor soils, eventually becoming unproductive.

The reduction of wind erosion from TT to CT is 41-76 per cent with 60 per cent on the average (Table 4). The change of TT to CT can reduce the losses of OM 120-360kg, N 10.2-20.4 kg, P 2.28-4.56kg and K 118-236kg per hm^2 per year.

Table 4. Comparison of Soil Wind Erosion in TT and CT Fields.

No	Place of measurement	Soil type	Amount of wind erosion			Method of measurement	Time of measure-ment
			TT	CT	Reduct-ion 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

3.2 Water Erosion

In the Yellow River basin, water erosion brings 1.6Bt soil into the sea each year, with average water erosion above 15 t/hm^2. Water erosion is more serious in sloping lands. As measured by the Shanxi Agricultural University, water erosion in 15^0 slope land is five times higher than in 5^o slope land.

With CT, moldboard plowing is not done, crop residues are left on the soil ground, and soil erosion is largely reduced resulting in the protection of soil productivity. CAU and other research units have measured the soil erosion in TT and CT systems. Results have shown that CT can reduce wind erosion on the average by 60 per cent and water erosion by 80 per cent（Table 5）. It is the same with wind erosion. CT can reduce large amounts of SOM, and N, P, K from water erosion.

Table 5. Water Erosion Comparison between TT and CT.

Place of measurement Unit	Field slope	Water erosion			Method	Time
		TT	CT	+- (%)		
Shouyang of Shanxi/ CAU	5^{o}	7.34 (t/hm^2)	1.45 (t/hm^2)	-80	Run-off plot, tipping bucket	1998-1999
Henan/ Academy of Luoyang Ag. Science	0^{o}	0.525 (t/hm^2)	0.123 (t/hm^2)	-76	Soil bin rainfall simulate	2000-2001
Shixian of Shanxi /Shanxi Ag. University	5^{o}	0.454 (g/s)	0.048 (g/s)	-88	Artificial slope rainfall simulate	1999
	10^{o}	3.327	1.154	-65		
	15^{o}	6.046	3.543	-41		

Aside from a reduction in soil erosion, the tons of crop residues returned to the field through CT, increases soil fertility and improves soil structure. CT cuts down tillage operations especially rotary hoeing.

CAU measured CT plots in Linfen City of Shanxi province, where wheat CT experiment plots for 15 years were studied. The SOM in CT fields in 1992 increased from 0.89 per cent to 1.31 per cent in 2005. Since then, every year, SOM increased by 0.03 per cent for 13 years from poor grade risen to middle grade. At the start of the experiments in 1992, there were no earthworms in the plots. After six years, the CT plots had 3-5 heads/m^2 of earthworms and 10-15 heads after 10 years. However, no earthworms were found in TT plots.

To control the decline in soil productivity, an accelerated extension of CT is necessary. It is better to have enough residue cover in the field surface at all times and less disturbance in the soil as much as possible.

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