

# The effect of conservation tillage on crop yield in China

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**Abstract** Traditional agricultural practices have resulted in decreased soil fertility, shortage of water resources and deterioration of agricultural ecological environment, which are seriously affecting grain production. Conservation tillage (CT) research has been developed and applied in China since the 1960s and 1970s, and a series of development policies have been issued by the Chinese government. Recent research and application have shown that CT has positive effects on crop yields in China. According to the data from the Conservation Tillage Research Center (CTRC), Chinese Ministry of Agriculture (MOA), the mean crop yield increase can be at least 4% in double cropping systems in the North China Plain and 6% in single cropping systems in the dryland areas of North-east and North-west China. Crop yield increase was particularly significant in dryland areas and drought years. The mechanism for the yield increase in CT system can be attributed to enhanced soil water content and improved soil properties. Development strategies have been implemented to accelerate the adoption of CT in China.

**Keywords** conservation tillage, crop yield, soil structure, development strategies

## 1 Background

Tillage has been synonymous with civilization for millennia, but traditional tillage-based farming practices result in accelerated erosion, degraded soil structure, and depletion of soil quality as well as nutrient status while increasing emissions of greenhouse gases (GHG) in many regions. Many of these problems can now be alleviated through the adoption of conservation tillage (CT), a sustainable land management system which can restore soil while increasing crop productivity, sequestering

carbon in soils, and reducing GHG emissions. In this article we investigated the effects of CT on crop yields in different cropping areas in China. Complete absence of tillage is often called no/zero-tillage, but reduced tillage or minimum tillage practices are also used. In this article, the term conservation tillage is used throughout to include no/zero-tillage, reduced/minimum tillage, controlled traffic and permanent raised bed practices.

### 1.1 Soil erosion and environment problems in China

China, which has the largest population in the world, faces a perpetual food security challenge. In the past 30 years, agricultural productivity and grain yield have improved rapidly, but conventional agricultural practices have resulted in soil degradation, resource shortages (e.g., water and fuel), aggravated drought and environmental deterioration, which seriously affect China's grain production and agricultural sustainability.

According to the National Bureau of Statistics of the People's Republic of China, arable land in China includes large areas with medium to low fertility, and the overall quality is not high. Per-capita water resource is only a quarter of the world's average, and groundwater has been seriously overexploited. Dryland farming areas account for about 60% of the total cultivated land, and the yield losses caused by drought account for two thirds of all losses caused by natural disasters. The land area prone to accelerated soil erosion is 3.56 million km<sup>2</sup> (about 37% of the total national territory), with serious losses of soil nutrients (such as C, N, P, and K). Long-term overuse of chemical fertilizers has led to declining soil fertility.

### 1.2 Promotion of conservation tillage worldwide

CT has been used to help address global food security challenges, and holds much promise in managing agro-ecosystems for improved and sustained productivity, increased profits while preserving/enhancing the resource base and environment<sup>[1,2]</sup>. These positive effects,

particularly improving crop yields, are significant in dryland farming areas. For example, no-till in combination with residue retention and crop rotation significantly increases crop productivity in dry climates, suggesting it might become an important strategy for adapting to climate-change in regions around the world as they become drier<sup>[3]</sup>.

Widespread implementation of CT in North/South America and Australia shows that significant farmer profitability can be achieved through a combination of sustained or increased agronomic productivity and reduced input costs. Similar agronomic benefits can be achieved for small to middle size farming areas in Asia and Africa for a broad array of crops despite marked differences in biophysical and socio-economic environments across these regions<sup>[4]</sup>. However, CT is a complex technology which requires lots of local knowledge and time to become effective. Some farmers may be unfamiliar with this new technology and give up when they see temporary decrease in crop yield<sup>[5,6]</sup>.

### 1.3 The policy of promoting conservation tillage in China

The Chinese government is paying considerable attention to the development of CT, and a series of associated policies (Table 1) have been issued. The Central No. 1 Document stressed development of CT for eight years from 2005 to 2012. The Ministry of Agriculture funded 30 million CNY each year to promote the research and extension of CT since 2002; in 2009, the China State Council ratified the National Construction Program of CT

formulated by the Ministry of Agriculture (MOA) and the National Development and Reform Commission (NDRC). This program promoted rapid development of CT in China. In 2005, the Ministry of Water Resources issued a policy outline for water-saving technologies in China, which aimed to promote CT. Also in 2005, the Ministry of Forestry issued a plan to further consolidate efforts to prevent and control desertification, mentioning CT as one of the main measures to manage desertified lands. The Ministry of Environmental Protection also issued a paper on environmental protection for the years 1996–2005, which promoted the development of CT in China.

## 2 The development of conservation tillage in China

The development of CT in China can be divided into four stages. The first stage (1960–1990) was the early period of CT research. In the 1960s and 1970s, some researchers began to study no-till planting technology, mainly concentrated in southern China. In the 1980s, the summer maize no-till planting technology developed quickly in northern China. In the 1990s, combining agricultural machinery and agronomy, China began systematic research on CT.

The second stage (1991–2000) was a period of research on the application of CT. From 1991 onward, to develop the means of CT implementation, the Conservation Tillage Research Center (CTRC), MOA, conducted research on

**Table 1** Some development policies of CT in China

Policy	Related Content
State Council: No. 1 Document (2005–2012)	Mandated the development of CT in China: e.g., reform of traditional farming methods, and develop conservation tillage; continuously implement demonstration programs of conservation tillage; continue to implement conservation tillage projects.
The Announcement of the Main Recent Works Aimed at Saving Society (2005)	Formulated a plan for implementing conservation tillage
Central Committee for Communist Party of China: Decision on Some Importance Issues of CPC Central Committee on Promoting Rural Reform and Development (2008)	Encouraged farmers to improve soil quality, extend rational fertilization and conservation tillage
Ministry of Agriculture: Demonstration Project for Conservation Tillage (2002–)	Funded 30 million CNY per year to promote CT research and extension
Ministry of Agriculture and National Development and Reform Commission: National Construction Program of Conservation Tillage (2009–2015)	Funded 1.2 billion CNY to construct 600 high standard CT regions
National Development & Reform Commission: China's Policies and Actions on Climate Change (2014)	Important agricultural measures to control greenhouse gas emission
The 11th Five-Year Plan for National Rural Economic and Social Development	Reform of tillage methods, and development of conservation tillage
Ministry of Water Resource: the Policy Outline for Water-Saving Technologies in China (2005)	Extending conservation tillage
Ministry of Forestry: Decision of the State Council on Further Consolidating Efforts to Prevent and Control Desertification (2005)	Promoted CT as one of the main measures to manage desertified lands
Ministry of Environmental Protection: White Paper of Chinese Environment Protection (1996–2005)	Promoted the development of CT

no-till seeders for small to medium-sized fields in mono-cropping areas of the Shanxi Loess Plateau. A light no-till seeder, characterized by a narrow opening, high clearance and double rows was developed. This equipment can prevent straw blockage, supply fertilizer deeply during no-till seeding and ensure higher yields in low fertility lands. The achievement of this no-till seeder laid a solid foundation for CT machinery development for mono-cropping areas in China. During this stage, a preliminary extension approach with a focus on fostering CT machinery specialized households, grain specialized households, and agricultural machinery service organizations was developed. A series of long-term CT experimental sites was established. The important progress in CT machinery design and tillage technologies proved that CT is not only suitable for China, but can also be implemented by mechanized operations in small and medium size fields.

The third stage (2001–2008) was the demonstration and extension of CT and the research on key technologies for representative cropping areas. In 2002, the MOA organized the first national CT field meeting, and displayed the research achievements of the second stage, indicating that CT can be used over large areas in China. In the same year, the MOA launched a demonstration project for CT, and began to extend CT in 38 counties of 8 provinces in northern China. In 2005, the MOA founded the national CT expert group. Provincial and county level CT expert teams were also set up to monitor the application and effects of CT in different cropping areas. In 2006, the MOA signed an agreement with the Beijing municipality, to fully implement CT in rural areas of Beijing within three years. By the end of 2008, CT had increased from 67000 hm<sup>2</sup> in 2002 to more than 2.6 Mhm<sup>2</sup>.

During this stage, in addition to further research in the Loess Plateau, CT machinery and technology with Chinese characteristics were developed for the North China Plain annual double cropping areas and North-east ridge tillage areas. The powered anti-blocking technology for no-tillage seeding, developed and completed in 1997 by the CTCRC, MOA, made it possible to seed wheat after maize with no/minimum tillage. This no tillage seeding technology was developed with the support of the 10th Five-Year National Scientific Research Projects, the MOA and provincial projects. Funded by the 11th Five-Year National Scientific Research Projects and the MOA projects, China began to research the CT technology and equipment for North-east China, and formed a set of no/minimum-till seeding technology for ridge tillage conditions.

The fourth stage (since 2009) has been to perfect CT technical modes in the Loess Plateau and North China Plain, as well as to strengthen the study of CT technology in the North-east, North-west and the Yangtze River basin areas of China. With the implementation of the National Construction Program of Conservation Tillage (2009–2015) by MOA and NDRC, and the MOA CT demonstration project, the technical support system for CT extension

has been gradually consolidated. The technical modes and no-till seeders have been upgraded in mono-cropping areas in the Loess Plateau. Summer maize no-till seeders in annual double cropping areas have been upgraded for improved anti-blocking and precision seeding. The efficacy of no/minimum tillage seeders in ridge-tillage areas has been improved. CT technical modes and equipment in North-west oasis agricultural areas and the Yangtze River basin areas have gradually developed.

### 3 The effect of conservation tillage on crops yields

According to the National Construction Program of Conservation Tillage and the MOA CT demonstration project, the extension of CT has been mainly in the north dryland areas (Loess Plateau, North China along the Great Wall), North China Plain, North-east and North-west regions (dryland area, oasis farming areas) due to various cropping systems, natural ecological conditions and other regional characteristics. Therefore the effect of CT on crop yields has been evaluated in these areas with data collected by the CTCRC, MOA (Table 2).

#### 3.1 North-east ridge tillage areas

The North-east ridge tillage areas consist of approximately 13.7 Mhm<sup>2</sup> of arable land located in the Liaoning, Jilin and Heilongjiang provinces, as well as eastern Inner Mongolia. Annual rainfall varies from 500 to 800 mm and the annual temperature varies from –5.0 to 10.6°C. The main soil type is vertisol. In this region, ridge tillage is the main farming system with the main crops being maize, soybean and rice, planted once per year. The major problem in the North-east ridge area is seasonal drought, especially spring drought. High annual cumulative evapotranspiration (four times that of annual rainfall) results in low soil moisture in root zones that limits crop production. Soil erosion and nutrient loss are also serious environmental issues. The objectives of CT are to slow down the decrease of soil fertility, reduce wind and water erosion, and conserve water to combat drought.

Sujiatun, Zhangwu and Fuxin are typical sites in this region. Several years' worth of data from these sites gave a mean maize yield of 9.65 t·hm<sup>-2</sup> under traditional tillage (TT) and 10.65 t·hm<sup>-2</sup> under CT, an increase of 10.5%, with individual increases ranging from 5.2% to 13.9%.

#### 3.2 North dryland areas

The data from the Loess Plateau and North China along the Great Wall were monitored. In this region, the annual rainfall varies from 250 to 450 mm, and annual temperature varies from 1 to 3°C. The main soil types are mollisol,

**Table 2** Mean crop yields ( $t \cdot \text{hm}^{-2}$ ) for traditional tillage (TT) and conservation (CT) at experimental sites around China

Areas	Site	Crop	Treatment		Increase
			TT	CT	
North-east ridge tillage areas	Sujiatun, Liaoning	Maize	9.94	10.46	5.2%
	Zhangwu, Liaoning	Maize	9.48	10.65	12.3%
	Fuxin, Liaoning	Maize	9.53	10.85	13.9%
North dryland areas (Loess Plateau, North China along the Great Wall areas)	Linfen*, Shanxi <sup>[7]</sup>	Winter wheat	2.04	2.81	37.7%
	Linfen*, Shanxi <sup>[8]</sup>	Winter wheat	3.05	3.25	6.6%
	Shouyang, Shanxi <sup>[9]</sup>	Maize	4.80	5.40	12.5%
	Wuchuan, Inner Mongolia <sup>[10]</sup>	Spring wheat	1.27	1.40	10.2%
	Lanxi, Inner Mongolia <sup>[11]</sup>	Maize	9.75	9.97	2.3%
	Fengning, Hebei <sup>[12]</sup>	Maize	5.88	6.27	6.6%
		Spring wheat	2.67	2.90	8.6%
North China Plain annual double cropping areas	Changping, Beijing <sup>[12]</sup>	Maize	7.03	7.21	2.6%
	Pingdu, Shandong	Maize	8.94	9.89	10.6%
		Winter wheat	5.79	6.08	5.0%
	Daxing*, Beijing <sup>[13]</sup>	Maize	5.78	5.93	2.6%
		Winter wheat	4.71	4.88	3.6%
	Daxing*, Beijing <sup>[14]</sup>	Maize	6.27	6.53	4.1%
		Winter wheat	4.77	4.85	1.7%
	Baodi, Tianjin <sup>[12]</sup>	Maize	7.33	7.29	-0.6%
		Winter wheat	6.11	6.16	0.8%
	Gaocheng, Hebei <sup>[15]</sup>	Maize	7.13	7.23	1.4%
		Winter wheat	5.73	6.00	4.7%
	Dingxing, Hebei <sup>[16]</sup>	Maize	8.90	9.40	5.6%
		Winter wheat	4.50	4.60	2.2%
	Shenze, Hebei	Maize	6.89	6.99	1.5%
		Winter wheat	4.92	5.03	2.2%
North-west dryland areas	Xinmi, Henan	Maize	8.70	8.88	2.1%
		Winter wheat	6.81	7.34	7.8%
	Weinan, Shaanxi	Maize	9.57	10.43	9.0%
		Winter wheat	6.12	6.38	4.2%
	Zhenyuan, Gansu	Winter wheat	6.02	6.56	9.0%
	Xifeng, Gansu <sup>[12]</sup>	Maize	6.90	7.33	6.2%
North-west oasis farming areas		Winter wheat	5.27	6.28	19.2%
	Zhangye, Gansu <sup>[17]</sup>	Maize	11.36	11.80	3.9%
		Spring wheat	5.90	6.00	1.7%

Note: The data are from published and unpublished sources by the CTCRC, MOA. \*, Different experiments in the same area.

inceptisol and alfisol. The main crops are corn, wheat, soybean and millet, planted once per year. Winter and spring drought, serious desertification and wind erosion are the main problems limiting crop yields. The application of CT in this region is to increase the surface roughness, reduce wind and water erosion, conserve water and increase water use efficiency.

Data from Zhangye, Wuchuan and Fengning, showed a mean maize yield of  $7.83 t \cdot \text{hm}^{-2}$  under TT and  $8.13 t \cdot \text{hm}^{-2}$  under CT, an increase of 3.8%. For wheat, a mean yield of  $2.52 t \cdot \text{hm}^{-2}$  under TT increased by 10% to  $2.81 t \cdot \text{hm}^{-2}$  under CT. Individuals experienced a greater increase in wheat yield (6.6%–37.7%) than maize yield (2.3%–12.5%).

### 3.3 North-west China

Oasis farming areas and dryland farming areas are the two main cropping areas in North-west China. North-west oasis farming areas include 164 counties of the total cultivated areas of 3.8 Mhm<sup>2</sup> in Xinjiang and Gansu, and parts of Ningxia Autonomous Region. The annual rainfall varies from 50 to 250 mm. The main soil types are inceptisol and alfisol. The main crops are maize, wheat, and cotton, which are mostly cropped once per year. CT in this region is used for reducing the quantity of irrigation water, improving water use efficiency and controlling wind erosion, thus dealing with the major problems of desertification and inefficient irrigation water consumption.

Several years of data collection in Zhangye indicated a mean maize yield of 11.36 t·hm<sup>-2</sup> under TT and 11.80 t·hm<sup>-2</sup> under CT, an increase of 3.9%. For spring wheat, the yield increase achieved under CT was only 1.7% (5.9 vs. 6.0 t·hm<sup>-2</sup>).

The North-west dryland farming areas occur in 195 counties totaling 7.8 Mhm<sup>2</sup> in Shanxi, Shaanxi, Ningxia, Qinghai and Gansu. The annual rainfall varies from 300 to 650 mm. The main soil types are ustochnept and calcic cryoboroll. The main crops are maize, wheat, and coarse cereals, planted once per year. The major problems in this region, which has a large proportion of hilly fields, are serious soil erosion and drought. CT should be applied to control soil erosion and reduce evaporation.

Zhenyuan and Xifeng are typical sites in this region. The mean winter wheat yield was 5.19 t·hm<sup>-2</sup> under TT and 5.63 t·hm<sup>-2</sup> under CT, an increase of 7.8% (Table 2). In Xifeng, mean maize yield under CT was 6.2% higher than under TT.

### 3.4 North China Plain annual double cropping areas

The North China Plain region includes 480 counties with 25.3 Mhm<sup>2</sup> of cultivated land, located in Beijing, Tianjin, south center Hebei, Henan, Shandong and northern Jiangsu. The annual rainfall varies from 450 to 700 mm. Two crops per year, winter wheat and summer maize, is the main cropping system in this region. CT focuses on the comprehensive utilization of crop residues as well as the reduction of excessive inputs, declining soil fertility and water shortages.

The mean maize yield was 7.9 t·hm<sup>-2</sup> under TT and 8.3 t·hm<sup>-2</sup> under CT, an increase of 4.2%. The mean wheat yield was 5.6 t·hm<sup>-2</sup> under TT and 5.8 t·hm<sup>-2</sup> for CT, an increase of 4.0% (Table 2). However, maize yield under TT (7.33 t·hm<sup>-2</sup>) was higher than under CT (7.29 t·hm<sup>-2</sup>) in Baodi.

The data from the above monitoring sites demonstrates that shifting from TT to CT can increase crops yields, and that this benefit was particularly significant in dryland farming areas, with yield increases of over 10%. However,

CT was not uniformly beneficial, for example in the North China Plain annual double cropping areas the increased yield for maize was higher than for wheat.

## 4 The mechanism of production increasing of CT

Recent studies in China and around the world have demonstrated that CT can improve soil structure and increase soil water content among other benefits. The following mechanisms are the key to increasing crop yields with CT.

**Improved soil physical and chemical properties.** In CT systems, crop residues are returned to the soil, which helps increase organic C and fertility. Straw return and zero tillage can sequester 5.96 and 9.76 Tg C per year, respectively<sup>[18]</sup>. It is estimated that 32.5 Tg C per year could be sequestered in croplands if no-till were to be adopted on 50% of the arable lands, and 50% of the crop residues were returned to the soil<sup>[19]</sup>. Soil organic matter can be decomposed and converted into humus under the influence of microorganism and earthworms. The increased organic matter in the soil improves the soil's ability to conserve water and nutrients, creating a more favorable environment for crop growth<sup>[20]</sup>. Hou et al. found that no-tillage and subsoiling (rotational tillage) can improve soil's physical and chemical properties, thus significantly increasing crop yields and water-use efficiency<sup>[21]</sup>. Hou et al. showed that no-tillage significantly decreased soil bulk density, improved total soil porosity and significantly increased the amount of 0.25 to 0.2 mm water-aggregates<sup>[22]</sup>. Kong et al. found that after an extended period of no-tillage soil tillage can improve soil physical properties and increase crop yield<sup>[23]</sup>.

**Reduced evaporation and surface runoff, and increased infiltration.** In CT systems, no-tillage and residue cover can reduce the rate of evaporation by shielding the soil from solar heating and ambient air temperature, and increasing soil's resistance to water vapor flux by reducing wind speed<sup>[24]</sup>. Furthermore, in CT fields, no-tillage and crop residue cover protect the soil from raindrop impact on surface aggregates, preventing pore sealing and crust formation; thus, no-tilled soil has a significantly lower surface runoff compared to traditionally tilled soil<sup>[25]</sup>. Huang et al. found that rainfall efficiency was up to 18% under no-till with stubble retained treatment compared to only 8% under TT with stubble removed<sup>[26]</sup>. Luo et al. found that reduced evaporation and surface runoff increase the opportunity for water to infiltrate<sup>[27]</sup>. Also, water infiltrates more easily into CT soils that have lower soil bulk density and better soil pore distribution as compared to TT soils.

**Increased soil water content.** Recent studies indicated that CT was effective in increasing soil water content and water use efficiency, and this positive effect was

particularly evident in dryland areas or in drought years when compared to TT. This can be attributed to improved soil capacity for conserving water, increased water infiltration, and reduced run off and evaporation. Fan et al. found that no-tillage soil contained between 2.5% (vol/vol) more water in the top 0–30 cm than when using a moldboard plough<sup>[28]</sup>. Chen et al. found that no-till with stubble retained had more water stable aggregation<sup>[29]</sup>.

In summary, improved soil properties and increased soil moisture are necessary for the improvement of agricultural productivity in mature CT systems as compared to TT systems.

## 5 Conclusions

CT is effective in increasing crop yields due to improved soil properties and increased soil moisture. This effect is particularly significant in dryland farming areas. Occasionally a lower crop yield is observed, as in Baodi, Tianjin, but generally CT results in a higher yield than TT. In the North China Plain annual double cropping areas, the mean crop yield increase can be over 4%; in mono-cropping systems in North dryland areas, North-east and North-west China, the mean yield increase can be over 6%. CT's positive effect on yields is a stimulus for its adoption in China and as of the end of 2014 it has been implemented in over 6.7 Mhm<sup>2</sup> of arable land. Generally, adoption of CT in China has been relatively slow with the following considered to be the main reasons.

CT systems need to be improved. Technical systems that apply to different cropping systems have not been fully established, and some promising technical systems for certain crops need to be perfected. Also, related key issues, such as high-performance CT machinery, highly-effective use of water/fertilizer, and highly-effective control of herbicide/pesticide need to be developed.

Farmers' understanding of CT needs to be strengthened. CT is more than a revolution of cultivation technology and brings with it changes to the cropping system and farm management practices. Given that yield increase and other comprehensive benefits from CT cannot be achieved immediately, farmers need the time to accept CT step by step.

The knowledge of extension staff and technicians need improvement. The extension of CT needs government support and guidance during the initial period. The current extension agencies and teams are insufficient for CT's adoption in large areas in China.

The long-term mechanisms of CT have not been established, which limits rapid extension of CT.

CT is both the main development direction of international agricultural technology and China's sustainable agricultural technology due to its resource saving and environment-friendly attributes. Future development of CT will include the following.

Technical bottlenecks (such as weed control, cropping systems, and water/fertilizer management) need to be solved for CT with national financial support based on regional characteristics of crops, soils and climates. Meanwhile, it must be recognized that CT is a long-term systematic project, and there may be no evident benefits in the short-term. Therefore, long-term projects (> 3 years) need to be launched for CT research and extension.

The quality and performance of machinery affects the extension and demonstration of CT. Therefore, it is recommended that research institutes, machinery-testing departments and agricultural machinery enterprises collaborate to improve the capability and adaptability of CT machinery.

The national subsidy policy for purchasing agricultural machinery should provide more support for the purchase of CT equipment.

Cooperation in agricultural machinery development and increases in key demonstration sites are needed to steadily extend CT.

For training, online information dissemination, seminars and experience-sharing sessions should be used to strengthen technical exchange, promote information sharing and expand the application of effective methods.

International cooperation and communication should be fostered. Actions such as formal international conferences, scientific exchange and advanced techniques training, will all be helpful in knowledge transfer from the large-scale farming systems in countries with well developed CT.

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