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Evolution of soil and water conservation in rain-fed areas of China

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Abstract

Rain-fed (dryland) farming is an ancient agricultural production system in China. It occurs widely across almost the whole country, especially in the Northwest and North China. The semi-arid Loess Plateau is the most important region of rain-fed farming in China, but unfortunately, soil erosion on the Loess Plateau area is the highest in China, and indeed amongst the highest in the world. This highlights the necessity for developing practices that can reduce soil and water erosion, improve soil water use efficiency, improve crop productivity, and reduce rural poverty in the region. Many techniques of soil and water conservation are being used in rain-fed areas of China, including such systems as mulch, ridge and furrow systems. The Appendix describes a unique system of soil and water conservation, called *Shatian*.

Modern research on conservation tillage (No Till), although essential for reducing erosion, increasing crop productivity, and ameliorating poverty, is just beginning in China. Modern conservation tillage research started in the1990s' with support from Australia and other countries. The procedures, however, were modified to be in accord with local conditions and prevailing farmer experiences. With 10 years of experimentation, results show that the most successful conservation practice on the Western Loess Plateau is no till with stubble retention. This technique helps to conserve soil water, increases soil organic carbon, improves soil structure and water infiltration, reduces soil and water erosion, and improves crop productivity and sustainability of rain-fed farming systems. However, its adoption rate remains low due to barriers such as traditional attitude, insufficient rural extension, and so forth.

Key Words: Soil and water conservation, Rain-fed agriculture, Gravel sand mulch, Conservation tillage, No till, Crop residue management, Soil carbon

1 Introduction

Rain-fed or dryland agriculture is an ancient agricultural production system in China, dating back approximately 8,000 to 9,000 years. Currently, rain-fed farming systems occur widely across most of the country, especially in the Northwest and Northern China. The arid and semi-arid regions account for about 52.5% of the total land area in China. The total arable land is about 120 million ha, of which about 80% are located in arid and semi-arid regions.

Rain-fed agriculture is the most widespread land use system in the semi-arid Loess Plateau (Wei & Wang,

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1999). Soil erosion is high to extreme in the Loess Plateau, due to intense thunderstorms during the summer-dominant rainfall period, the low soil aggregate stability, and the poor vegetative cover of the loess soils (Huang et al., 2006). Soil erosion is the highest in China (Liu, 1999), and indeed it is amongst the highest in the world (Fu, 1989). Serious soil erosion in this area leads to high nutrient losses and low soil water use efficiency, resulting in low crop yields, and fragile agricultural production systems highly susceptible to droughts. It also results in high sediment yields in downstream areas, and negative environmental impact (Huang, 2003). Therefore, developing techniques that can reduce soil and water erosion, improve soil water use efficiency, impart some degree of drought proofing, and improve the environmental impacts is critical to sustained crop production in this region.

China has a long history of practices of conservation agriculture (Huang, 2003), but systematic research on modern soil conservation commenced only in the 1990' s. This paper reviews the status of soil conservation measures in China, and describes some research on modern conservation tillage and its adoption. An interesting ancient, but still used practice of soil and water conservation, called *Shatian*, is described in the Appendix.

2 The status of soil erosion and control in China

A national census of soil erosion and soil conservation was completed in China in 2010−2012 (Liu, 2013). The results showed that the total area of soil loss was approximately 2.95×10^8 km^2 of which 44% was attributed to water erosion and 56% to wind erosion. Water erosion occurred mainly in high population areas and on the Loess plateau, while wind erosion mainly in Northwest China. This level of erosion, although extensive, is still a total reduction of 17.1% since the Second National Survey in 2002, with water erosion reduced by 21.7%, and wind erosion reduced by 13.2% (Liu, 2013). The greatest reductions were in slight and moderate water erosion areas, and in severe and extreme wind erosion areas.

Severe erosion persisted in the upper and middle reaches of the Yangtze and Yellow Rivers, the black soil region in Northeast China, and the mountainous regions in Southwest China. However, the results also showed that in Eastern China, with relatively advanced economies and higher living standards, erosion was brought under control, probably because of improved living standards, and people demanded better water quality and good ecological living conditions.

The 2013 census also catalogued the type, area, and distribution of soil and water conservation measures. The results showed that approximately 9.9×10^5 km^2 benefited from soil and water conservation measures, with 20% benefiting from engineering measures, 78% from biological measures, and 13% from other measures (Liu, 2013). However, the areas benefiting from conservation measures declined, due mostly to the occurrence of natural hazards, such as droughts and floods, and extensive construction projects.

Since the 1980s, the Government of China has identified the Loess Plateau and the Yangtze River basin as strategic areas for erosion control, with corresponding policies and programs to mitigate erosion. Results of the 2013 census illustrated some successes achieved, whereby erosion decreased by17.9%−44.95%, depending on the area (Liu, 2013). Regardless, the Loess Plateau continues to experience high rates of water erosion and gully formation, in fact some of the highest in the world. Engineering approaches, such as terraces, water diversion channels, sediment traps, etc., provide partial solutions to the problem, but even after decades of using such techniques, the evidence is that simple solutions will not work for such complex problems. Current efforts are to integrate these engineering approaches with better biological and ecologically based solutions, including Conservation Tillage and No Tillage. In this paper, we use these two terms interchangeably.

3 Modern conservation tillage (no till)

3.1 *The necessity for use of conservation tillage (CT) on the Loess Plateau*

The severe soil erosion on the Loess Plateau is a serious and continuing problem contributing to environmental pollution and uncertainty of food security and poverty in the region. The reasons are many, among which the use of traditional agricultural practices is one of the leading causes. These traditional practices normally involve plowing (moldboard) three times and harrowing twice between harvest and spring sowing. Thus, the soil surface is left uncovered during the 7-8 month fallow period, which includes part of the rainy season. Also, all stubble and residues are removed from the fields at crop harvest for use as forage, fuel, etc. The combination of these practices leaves the soil highly vulnerable to the erosive influence of wind and water during this critical period, resulting in extensive erosion and degradation of the soil, and reduced production potential. Consequently, local farmers are trapped in a cycle of soil degradation and poverty.

These severe erosion and poverty problems have been recognized by central and provincial governments. Addressing rural poverty and improving the environment across the Loess Plateau has been a priority of government policy over the past several decades (MOA, 2001). In Gansu, provincial strategies aim to reduce farmer reliance on grain production (wheat, potato, field peas etc. are the main crops), increase the production of cash crops and livestock, and relocate farming villages to more fertile lands (Feng et al., 2003; MOA, 2001). However, implementation has met with some resistance on the western Loess Plateau, as the area has a tradition of crop cultivation for several thousand years, and local farmers are reluctant to convert their cropland to grass and forestry (Rui et al., 2002; Shi & Shao, 2000; Zhang et al., 2004). Therefore, development of farmer friendly agronomic practices is needed to empower the farmers as partners to reduce erosion, increase crop productivity, ameliorate poverty, and improve the environment.

Conservation tillage (CT), developed in the USA, Canada and the UK to combat soil loss and preserve soil moisture, represents the most dramatic change in soil management in modern agriculture (Bradford & Peterson, 2000); in recent years, this has received increased attention around the world. Modern CT research in China started from the 1990s; in 1992, the China Agricultural University, in cooperation with the University of Queensland and Shanxi Farm Machinery Bureau, started conservation tillage trials in Shanxi Province (Gao & Li, 2003). Preliminary results from this research showed that conservation tillage can help to ease environmental problems, improve crop productivity, and enhance the sustainability of rain-fed agriculture in the region (Huang, 2003; Li et al., 2004).

3.2 *Main effects of conservation tillage in rain-fed areas on the Loess Plateau*

Following the success from Shanxi Province and to promote conservation tillage in the western Loess Plateau, Gansu Agricultural University, in cooperation with the University of Adelaide, CSIRO, and NSW Department of Agriculture of Australia, started conservation tillage trials in Gansu Province in 2001. A long term conservation tillage experiment was established in Dingxi, Gansu Province, to determine the effects of conservation tillage on soil chemical, physical and biological processes, as well as on crop productivity and profitability.

3.2.1 Materials and methods

Site description

The field experiment was conducted at the Dingxi Experimental Station (35°28′N, 104°44′ E, elevation 1971 m a.s.l.) of Gansu Agricultural University, in Lijiabu Village, Anding County, Dingxi, Gansu Province, northwest China. The soil at the experimental site is called Huangmian, in the Chinese soil taxonomy (Chinese Soil Taxonomy Cooperative Research Group, 1995) and Calcaric Cambisols in the FAO soil map of the world (FAO, 1990). This soil, typical of the major cropping soils of the Loess Plateau, is sandy-loam with low fertility (Table 1; Zhu et al., 1983). Average annual rainfall at Dingxi is 391 mm, ranging from 246 mm in 1986 to 564 mm in 2003. On average, about 54% of annual rainfall is received between July and September. Daily maximum temperatures can reach up to 38 ℃ in July, while minimum temperatures can drop to －22 ℃ in January. Hence, summers are warm and moist, whereas winters are cold and dry. Accumulated temperature above 10 ℃ averages 2,239 ℃ over the year, average radiation is 5,929 MJ m^{-2}, and sunshine hours are 2,477 hours per year. The site had a long history of continuous cropping using conventional tillage. The previous crop prior to commencement of the experiment in 2001 was flax (Linum usitatissimum L.).

Table 1 **Soil chemical and physical properties at the start of experiment**

Depth (cm)	pH (water)	Organic carbon (g kg^{-1})	Total N (g kg^{-1})	Total P (g kg^{-1})	Olsen P (mg kg^{-1})	Available K (mg kg^{-1})	Bulk density (Mg m^{-3})
0-5	8.3	7.63	0.85	1.89	13.3	349.6	1.29
5-10	8.4	7.46	0.87	1.92	11.5	330.2	1.23
10-30	8.3	6.93	0.78	1.82	4.9	244.0	1.32
30-50	8.3	6.63	0.78	1.72	1.8	173.0	1.20
50-80	8.3	7.29	0.81	1.71	2.1	123.1	1.14

Continued

Depth (cm)	pH (water)	Organic carbon (g kg^{-1})	Total N (g kg^{-1})	Total P (g kg^{-1})	Olsen P (mg kg^{-1})	Available K (mg kg^{-1})	Bulk density (Mg m^{-3})
80-110	8.4	7.49	0.80	1.75	2.1	101.5	1.14
110-140	8.4	6.60	0.73	1.71	1.6	102.5	1.13
140-170	8.4	6.51	0.66	1.71	1.8	102.0	1.12
170-200	8.4	6.15	0.59	1.70	2.2	104.1	1.11

3.2.2 Experimental design and treatments

The experiment had 6 treatments, 2 phases, replicated 4 times (blocks). Spring wheat (cv. Dingxi No. 35) and field pea (cv. Yannong) were sown in sequence in both phases each year. Phase 1 started with spring wheat, followed by field pea, and phase 2 started with field pea, followed by spring wheat. There were 48 plots in total, each plot being 4 m wide by 17 m long in block 1, 21 m long in blocks 2 and 3, and 20 m long in block 4.

Treatments

Treatment 1: *Conventional tillage with no stubble* (T). The seedbed was prepared with three sequences of plowing and two of harrowing using animal power, followed by sowing with the no-till seeder. The first cultivation started immediately after harvest, the second before winter and the third prior to sowing in spring (cultivation depth 10–20 cm). Harrowing was carried out prior to sowing in the spring. All stubble was removed before cultivation. This treatment represents the typical tillage practice in the western Loess Plateau.

Treatment 2: *No-till with no stubble* (NT). No cultivation was performed throughout the season. The crops were sown with the no-till seeder, but all stubble was removed at crop harvest.

Treatment 3: *Conventional tillage with stubble incorporated* (TS). Cultivation was the same as treatment 1, but all stubble from the previous crop was returned to the original plot immediately after threshing and then incorporated into the soil with the first cultivation. In 2001, chopped wheat straw (5-10 cm in length) was used at 6.8 t ha^{-1} for both crops. The crops were sown with the no-till seeder.

Treatment 4: *No-till with stubble retention* (NTS). No cultivation was performed throughout the season, but stubble from the previous crop was retained on the soil surface but without incorporation. Chopped wheat straw was used as described in treatment 3 in 2001. The crops were sown with the no-till seeder.

Treatment 5: *Conventional tillage with plastic film mulching* (TP). Plots were cultivated 3 times and harrowed 2 times before the plastic film (0.5 mm thick) was laid out in October. All the stubble was removed before cultivation. A clear, white, plastic film (0.5 mm thick) was used and laid out using the local seeder. The same seeder was used to sow both spring wheat and field pea.

Treatment 6: *No-till with plastic film mulching* (NTP). No cultivation was carried out throughout the season, and stubble was removed before the plastic film (0.5 mm thick) was laid out in October. The crops were sown by the local seeder.

3.2.3 Field management

All crops in T, NT, TS and NTS were sown with a small no-till seeder (5-6 rows in 1.2 m width) designed by the China Agricultural University. The no-till seeder, drawn by a 13.4 kW (18 HP) tractor, was designed to place fertilizers below the seeds on one operation using narrow points followed by concave rubber press wheels. For TP and NTP, all crops were sown by a seeder designed locally. The local seeder, drawn by animal power, was designed to form the ridge, lay the plastic film, sow the seeds and apply fertilizer in one operation.

Sowing rate. Spring wheat was sown at 187.5 kg ha^{-1} in mid-March and harvested in late July to early August each year. Field pea was sown at 180 kg ha^{-1} in early April, and harvested in early July each year. The row spacing was 20 cm for spring wheat and 24 cm for field pea for all treatments in group 1. In group 2, each crop was sown in paired rows on both sides of the furrow, 10 cm apart. Thus, the crop row spacing was 10 and 40 cm alternately, averaging 25 cm.

Fertilizer treatment. Nitrogen and phosphorus were applied at 105 kg N ha^{-1} as urea (46% N) and at 45.9 kg P ha^{-1} as calcium superphosphate (6.1% P) for spring wheat, and 20 kg N ha^{-1} and 45.9 kg P ha^{-1} for field pea. No farm manure was used in the experiment. Field peas were not inoculated when sown as no appropriate rhizobia were available on the market. However, the site has a history of field pea being grown in the past 3 years.

Weed and pest management. Roundup® (glyphosate, 10%) was used for weed control during fallow after harvesting as per the product guidelines. During the growing season, weeds were removed by hand. Pests and diseases were monitored and controlled as per conventional practices in the area. The plastic film was removed from plots after the crops were harvested for treatments TP and NTP.

3.2.4 Field data collection

Grain yield: The plot was harvested manually with sickles at 5 cm above ground. The edges (0.5 m) of the plot were trimmed and discarded. Samples were separated into grain yield, straw and chaff. All straw and chaff from stubble incorporated treatment and stubble retention treatments were returned to the original plots immediately after threshing.

Soil moisture: A 2-m long aluminum access tube was installed in each plot at initiation of the experiment. Soil moisture was measured using a Neutron Moisture Metre (NMM, Campbell Pacific, CPN 503) every two weeks at 10-30, 30-50, 50-80, 80-110, 110-140, 140-170 and 170-200 cm, and calibrated following the procedure described by Greacen and Hignett (1979). The soil moisture contents at 0-5 and 5-10 cm were measured gravimetrically every two weeks. The drained upper limit and crop lower limit of water extraction were determined as described in Dalgliesh and Cawthray (1998).

Soil nitrogen: Soil samples were taken at 0-5, 5-10, 10-30, 30-50, 50-80, 80-110, 110-140, 140-170 and 170-200 cm before sowing and after harvest each year, ten cores per plot for the top 3 depths, bulked into one sample for each plot, and one core for the remaining depths for each plot. Nitrate nitrogen (NO_3^-−N) in the soils was determined using $FeSO_4$/Zn reduction method described in ABARE (1993).

Plant nitrogen: Nitrogen in grain and crop residues (straw and chaff) were determined using the method described by Lu (2000).

Nitrogen fixation by field pea was estimated using the method of N^{15} natural abundance as described by Armstrong et al. (1994). At antithesis, 5 individual field pea plants were cut at the ground level from each plot, bulked into one sample and dried at 60 ℃ for 24 hours. At the same time, 5 non-legume plants (weeds) from the plot were also collected and oven-dried at 60 ℃ as “reference plants”. Both the legumes and reference plants were ground through 1 mm mesh, then sub-sampled and finely ground prior to analysis of N^{15} natural abundance using continuous flow isotope ratio mass spectrometry (Dawson & Brooks, 2001). Nitrogen fixation was measured only once in 2005.

3.2.5 Calculations

Soil water storage (mm) at a given depth increment was calculated as the volumetric soil moisture (%) multiplied by depth of soil (cm) divided by 10. The total soil water storage for the whole profile (mm) was the sum of soil water storage for all depth increments.

Evapotranspiration (ET, mm) was calculated as the difference between the precipitation (mm) and the change in soil water storage (mm) over the observation period. There was no runoff observed during the period of experiment. The soil water content at depth never approached the drained upper limit and so it could be assumed there was no drainage.

Water use efficiency (WUE, kg ha^{-1} mm^{-1}) was calculated as grain yield divided by ET. Fallow efficiency was calculated as the percentage of stored soil water over total rainfall during the fallowing period (Felton et al., 1987).

Nitrogen fixation by field pea was calculated as follows:

$$\%Ndfa = 100 \times \frac{\delta^{15}N(weeds) - \delta^{15}N(legume)}{\delta^{15}N(weeds) - B} \quad (1)$$

where $\%Ndfa$ is the percentage of plant total N derived from fixation; $\delta^{15}N(weeds)$ is natural abundance of ^{15}N in reference plant (weeds); $\delta^{15}N(legume)$ is natural abundance of ^{15}N in legume (field pea), and B represents a measure of the isotopic fraction associated with redistribution of N between roots and shoots.

Nitrogen use efficiency(NUE) for spring wheat was calculated as follows:

$$NUE = 100 \times \frac{Plant\ N\ uptake}{NO_3^- N\ at\ sowing + Fertiliser\ N}\% \quad (2)$$

In this calculation, NH_4-N was not included as the amount of NH_4-N was negligible. Nitrogen mineralized from soil organic matter during the growing season was also not included.

Nitrogen balance was calculated over 4 years with two complete rotation cycles. Nitrogen inputs included N in fertilizers and N in seeds. The N in straw brought into the system (6.8 t ha^{-1}) in 2002 was also taken into account for TS and NTS treatments. Total N output included grain N and stubble N if stubble was removed (e.g. T, NT, TP and NTP treatments). Nitrogen fixed by field pea in 2001−2004 was extrapolated using data in 2005 as no data were available in 2001−2004.

4 Results

Conservation of soil water: The different conservation tillage patterns had no strong effect on total soil water storage (0-200 cm). However, the ratio between plant transpiration and soil evaporation of NTS increased significantly, thus grain yield and water use efficiency(WUE) of NTS were improved significantly compared with conventional tillage (Li et al., 2005). This research highlighted that no till with stubble retention could considerably increase surface (0-10 cm) soil moisture at sowing on the Western Loess Plateau. This is important for crop emergence, but also to mitigate against the spring droughts which are frequent in the area (Table 2).

In conservation tillage, retaining residues on the soil surface provides cover to reduce evaporation and runoff, and improves rainfall infiltration (Franzluebbers, 2002; Lampurlane’s & Cantero-Martínez, 2006).

Table 2 Soil water profile at sowing under different no till with stubble retention treatments compared with conventional tillage (V%)

Crop	Depth (cm)	2002		2003		2004	
		T	NTS	T	NTS	T	NTS
Wheat	0-5	10.2	19.5	7.0	12.4	15.7	20.2
	5-10	15.2	20.1	9.6	13.5	19.9	21.1
	10-30	20.1	21.5	15.3	16.2	19.9	20.2
	30-50	15.1	16.3	13.5	13.7	19.2	20.0
	50-80	13.3	13.9	13.4	13.2	18.2	18.8
	80-110	14.0	13.4	13.6	14.0	17.7	17.4
	110-140	14.8	14.0	14.2	14.2	17.2	17.9
	140-170	15.9	14.9	15.6	14.9	16.6	17.4
	170-200	16.1	16.2	15.0	15.6	17.0	16.8
Field pea	0-5	16.9	21.8	14.2	22.1	9.9	11.0
	5-10	23.3	24.3	17.1	21.3	18.4	19.4
	10-30	21.4	22.5	14.3	16.9	20.0	21.7
	30-50	15.3	16.9	11.8	12.1	19.1	19.3
	50-80	13.6	14.9	12.4	11.3	18.4	19.2
	80-110	13.6	14.1	13.7	12.3	17.2	18.2
	110-140	14.8	14.7	14.2	13.3	16.2	17.2
	140-170	16.1	15.2	15.6	14.1	16.0	16.5
	170-200	17.0	16.5	15.5	15.2	17.1	16.2

Increase in Soil Organic Carbon: Total organic carbon (TOC) and readily oxidizable organic carbon (ROOC) decreased with soil depth, but not uniformly with all treatments (data not shown). The average content of TOC and ROOC in the 0-30 cm soil depth over the 12 years for the different treatments was NTS>TS>NTP>NT>T>TP. Compared with T, the average ranges of TOC and ROOC under NT, NTS, NTP and TS increased respectively by 1.2%-7.2% and 5.3%-16.6%. Both no till and straw mulching increased TOC and ROOC contents, but the NTS treatment provided the optimum result. Compared with 2002, the average contents of TOC and ROOC under NTS increased respectively by 9.5% and 42.9%, 13.2% and 67.6%, 21.5% and 71.5%, 1.1% and 15.9%, 2.7% and 12.6% in 2004, 2006, 2008, 2010 and 2012. ROOC was more sensitive to tillage practices than TOC (Table 3 and Table 4), and thus it was used as an early indicator for changes in soil organic carbon in loess soil of the western Loess Plateau.

It is well-known that additions of organic matter, such as manures, composts, above-ground crop residues, below-ground crop residues, microbial biomass, etc. can improve soil organic carbon (Loveland & Webb, 2003). No till and/or minimum till reduce soil compaction and minimize soil organic matter decomposition.

Table 3 Dynamic changes of total organic carbon (TOC) in the soil layer of 0-30 cm under different tillage practices (g kg^{-1}) ($P<0.05$)

Treatment	Year						Mean
	2002	2004	2006	2008	2010	2012	
T	8.89a	8.26c	8.07b	8.62c	7.61ab	7.70c	8.19b
NTS	8.13c	8.9a	9.20a	9.88a	8.22a	8.35b	8.78a
NT	8.64a	8.39bc	8.13b	8.64c	7.60ab	8.34b	8.29b
TS	8.54ab	8.61ab	8.83a	8.93bc	7.67ab	8.82a	8.57a
TP	8.16bc	8.19c	7.52c	7.96d	7.42b	7.80bc	7.84c
NTP	8.49ab	8.16c	8.31b	9.37b	8.11ab	8.14bc	8.43b

Table 4 Dynamic changes of readily oxidizable organic carbon (ROOC) in the soil layer of 0-30 cm under different tillage practices (g kg^{-1}) ($P<0.05$)

Treatment	Year						Mean
	2002	2004	2006	2008	2010	2012	
T	4.04ab	4.65b	5.58bc	5.59b	3.87ab	3.32c	4.51bc
NTS	3.89b	5.56a	6.52a	6.67a	4.51a	4.38ab	5.26a
NT	4.04ab	4.90b	5.41c	5.61b	3.90ab	4.66a	4.75bc
TS	4.12ab	4.92b	6.10ab	6.08ab	3.75ab	4.31ab	4.88ab
TP	3.84b	4.62b	5.23c	5.49b	3.62b	3.54bc	4.39c
NTP	4.49a	4.87b	5.74bc	6.19ab	4.13ab	3.62bc	4.84ab

Improving Soil Structure and Increasing Soil Water Infiltration: Measurements of changes in some soil physical properties, made in 2007 in the top 30 cm on the Loess Plateau, showed that although NTS had no strong effect on soil bulk density and total porosity, the non-capillary porosity and soil aggregates (>0.25 mm) under NTS were significantly increased (Table 5). Thus, soil saturated conductivity was much improved (Fig. 1), and soil infiltration was increased.

Table 5 Soil physical properties under different tillage systems in 2007 ($P<0.05$)

Depth (cm)	Treatment	Bulk density (g cm^{-3})	Total porosity (%)	Capillary porosity (%)	Non-capillary porosity (%)	Aggregates＞0.25mm (%)
0-5	T	1.24a	53.09b	48.70a	4.39b	14.90b
	NT	1.21ab	54.40ab	49.10a	5.30ab	14.57bc
	TS	1.15b	56.47a	49.81a	6.67a	10.28d
	NTS	1.22ab	53.94ab	47.62a	6.31a	16.53a
	TP	1.23ab	53.53ab	49.65a	3.96b	10.98d
	NTP	1.22ab	53.97ab	49.66a	4.31b	13.57c
5-10	T	1.26a	52.54a	48.92a	3.62b	6.87d
	NT	1.21a	54.28a	49.07a	5.21ab	8.58c
	TS	1.25a	52.87a	47.68a	5.20ab	10.15b
	NTS	1.25a	52.72a	46.94a	5.78a	12.22a
	TP	1.24a	53.14a	49.52a	3.63b	5.82e
	NTP	1.22a	53.99a	49.90a	4.09ab	11.47a
10-30	T	1.32a	50.22a	46.59a	3.63b	7.55cd
	NT	1.25a	52.73a	48.15a	4.58ab	8.50bc
	TS	1.31a	50.71a	46.35a	4.37ab	11.82a
	NTS	1.28a	51.85a	46.89a	4.96a	11.68a
	TP	1.27a	52.13a	48.63a	3.50b	6.60d
	NTP	1.26a	52.58a	48.97a	3.61b	8.85b

Soil water infiltration is determined by soil structure and soil aggregate stability. The favorable effect of conservation tillage systems on soil structure has been reported in different soil types and climates (Oyedele et al., 1999). In contrast, conventional tillage promotes loss of soil organic matter, which leads to disruption of soil aggregates and increased erosion (Roldán et al., 2003). The crop residues in conservation tillage protect the soil from raindrop impact, reduce slaking of surface aggregates, and prevent pore sealing and crust formation. Crop residues left on the soil also reduce surface flow and runoff, and increase the opportunity for water to infiltrate. The combination of these beneficial effects of residues increases water infiltration (Potter et al., 1995).

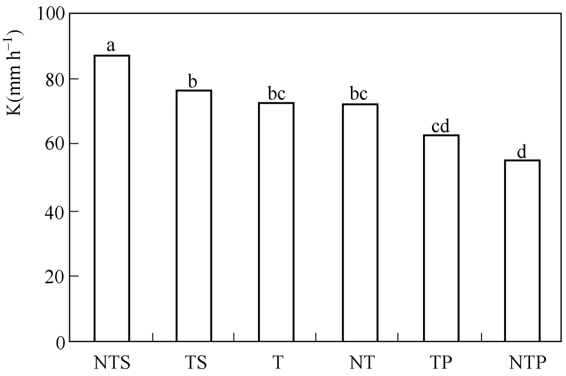

Fig.1 Soil saturation conductivity under different tillage systems

Reducing Soil and Water Erosion: Data from rainfall simulation on soils of the western Loess Plateau showed that cumulated infiltration was significantly increased and runoff was decreased by no till with stubble retention, and soil loss (sediment load) from erosion was reduced by 62.4% (Table 6).

Runoff and soil loss are problems common to most croplands in the world, especially those with unstable soil aggregates in the surface soil horizons, and this causes serious problems in terms of agricultural productivity and environmental quality (Rhoton et al., 2002). Conservation tillage, with surface residue mulches, provide soil cover that reduces rainfall impact and protects against runoff (Franzluebbers, 2002), thus reducing soil erosion, sediment loads, and improving water quality.

Table 6 Cumulated runoff, infiltration and sediment under different tillage systems ($P<0.05$)

Treatment	Rainfall (mm)	Cumulated runoff (mm)	Cumulated infiltration (mm)	Sediment (g m^{-2})
T	85	53.10b	31.90b	27.77ab
NT	85	62.90a	22.10b	32.73a
TS	85	66.26a	18.74c	23.79b
NTS	85	44.85c	40.15a	14.89c

Increasing Crop Productivity: The long term research on the western Loess Plateau of China showed that grain yield under no till with stubble retention (NTS) was generally higher than under conventional tillage. It also illustrated the partial drought proofing advantage of adopting NTS in drier years (2003, 2007) (Table 7).

Adopting conservation tillage without conserving crop residues had no effect on yield (NT vs. T; NTP vs. TP), but a combination of no-tillage and straw conservation tended to increase yields (NTS vs. NT) of wheat (Table 7). The water conserving effect of maintaining crop residue on the soil surface ensures at least some degree of yield and often a substantial yield advantage when drought stress is an issue (Huang et al., 2008). The organic matter used in crop residue mulch, however, has different short-term implications, typically depending on the quality of organic matter as reflected by the C: N-ratio. Crop residue mulch also helps to control crop weeds, pests and diseases.

Table 7 Grain yield under different tillage systems (kg ha^{-1}) ($P<0.05$)

Rotation	Year	Annual rainfall (mm)	Crop	T	NT	TS	NTS	TP	NTP
Pea→Wheat	2002	351	pea	1,652.82a	1,416.28c	1,526.77b	1,789.72a	1,614.00ab	1,528.72b
	2003	565	wheat	1, 16.05d	1,544.73d	1,645.75cd	1,825.48b	2,033.07ab	2,139.88a
	2004	332	pea	1,708.21a	1,495.58a	1,681.25a	1,667.59a	1,761.66a	1,511.93a
	2005	453	wheat	2,900.22b	3,076.55ab	2,987.52b	3,327.09ab	3,277.31ab	3,578.38a
	2006	392	pea	758.55bc	551.72c	871.94ab	890.21ab	1,019.53ab	1,049.07a
	2007	387	wheat	561.53c	633.47bc	666.30bc	943.87a	731.79b	926.44a

Continued

Rotation	Year	Annual rainfall (mm)	Crop	T	NT	TS	NTS	TP	NTP
Pea→Wheat	2008	427	pea	1,342.02ab	1,306.20ab	1,190.23b	1,660.72a	1,062.80b	1,250.14ab
	2009	320	wheat	1,232.54bc	985.39c	1,670.43a	1,607.15ab	1,470.76ab	1, 241.05bc
	2010	326	pea	1,353.04ab	1,240.26b	1,445.90a	1,434.88a	1,419.33a	1,472.82a
	2013	466	wheat	1,228.65b	1,419.26ab	1,525.90ab	1,723.34a	1,468.38ab	1,857.48a
	Sum			14,154	13,669	15,212	16,858	15,825	16,597
Wheat→Pea	2002	351	wheat	1,816.05b	1,413.50c	1,735.75b	2,150.67a	1,385.39c	1,258.42c
	2003	565	pea	881.35bc	803.15c	823.07c	1,269.47a	1,061.76b	1,022.31b
	2004	332	wheat	2,188.94b	1,664.10c	2,162.09b	2,381.99a	2,625.36a	2,170.90b
	2005	453	pea	1,686.46b	1,816.20ab	1,911.06ab	2,119.33a	1,980.09ab	2,148.07a
	2006	392	wheat	1,428.31bc	1,316.51c	1,564.79b	1,548.74b	1,846.97a	1,820.66a
	2007	387	pea	205.59cd	276.86bc	341.86b	552.61a	179.87d	248.72cd
	2008	427	wheat	1,631.59a	1,818.22a	1,851.35a	2,100.06a	2,135.52a	1,857.56a
	2009	320	pea	761.93a	727.48a	857.41a	872.79a	737.99a	862.85a
	2010	326	wheat	1,356.50b	1,365.10b	1,482.00b	1,647.83ab	2,377.73a	2,100.07a
	2013	466	pea	839.44c	1,050.56b	1,052.39b	1,428.24a	1,106.04b	1,240.80b
	sum			12,796	12,252	13,782	16,072	15,437	14,730

5 Conclusions

Severe erosion in China, especially on the semi-arid Loess Plateau, highlights the necessity for widespread adoption of conservation tillage. In addition, because of the strong environmental, economic and social concerns on the impacts of soil erosion, agricultural productivity, and water quality, the adoption of this technique is critical for China.

The benefits of conservation tillage (no tillage) is gaining acceptance in many parts of the world in terms of enhancing global sustainable agriculture (Kassam et al., 2012). However, adoption of conservation tillage practices in China has been slow in comparison with the global average (Kassam et al., 2009). Preliminary findings of a long term tillage experiment in the semiarid Loess Plateau region of China indicates that no-till with stubble retention (NTS) conserves soil moisture, increases soil organic carbon, especially readily oxidizable organic carbon, improves soil structure and increases soil water infiltration, reduces soil erosion, increases water use efficiency and crop productivity and sustainability. The evidence is that no till with conserved stubble is the best conservation agriculture practice for the rainfed Loess Plateau. However, because modern conservation tillage is still a new technology in China, and because of the barriers preventing adoption, the total area under conservation tillage remains low.

The challenges in adopting conservation tillage in China include the following:

- *traditional attitude*. Intensive cultivation has been practiced in China for thousands of years. Despite clear benefits from conservation tillage, there is still a strong belief among farmers that cultivation is necessary for successful seed germination and crop production. Even when confronted with the evidence, this attitude tends to prevail and thus impedes adoption of conservation tillage.
- *insufficient research and extension*. Although China has a long history of soil and water conservation (Huang, 2003), modern conservation tillage is new in China. Therefore, there is a great need for innovative and supportive research in conservation tillage in different environments to provide the data and demonstrate the results.
- *lack of machinery tailored to conditions in China*. Specialized machinery (direct drill) is necessary for sowing and harvesting under conservation tillage, and these are still not universally available in China. The largest proportion of cultivatable land in China is unsuitable for large tractors, especially on the Loess Plateau, because of the difficult terrain. The large machines developed in USA, Australia, and elsewhere are not suitable, without modification, for the small farms in China.

- *high opportunity cost of straw/residue*. On the Western Loess Plateau, crop stubble and stalks are used as fuel for cooking and heating, and/or as feed for animals. This is a necessary part of the farming systems in China, and will remain an obstacle to adoption of conservation tillage until suitable, affordable substitutes for feed and fuel are available.

According to Wang (2012), and MOA (2001), the area under conservation tillage in China exceeds 6.67 Mha. However, this is only about 5.5% of total arable and permanent cropland area in the country. Therefore, for a more sustainable agriculture in the rain-fed areas of China, demonstration and extension will be required for many years to overcome traditional beliefs and adapt conservation agriculture to local conditions. In addition, systematic and practical research on ecological, economical, and social impacts of conservation tillage is also essential to successfully shift from traditional to conservation tillage.

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Appendix

The Shatian system of soil conservation

Soil and water conservation practices in China date back hundreds of years. Many techniques of soil and water conservation have been used in rain-fed areas of China, the most common being mulch. Materials used as mulches often depended on what was available, but included crop residues (i.e., stubble mulch), gravel, sand, plastic film, and poultry and livestock manures. Other soil conservation techniques included ridge and furrow systems, concrete layers, and so forth. These practices were used successfully for vegetables and fruits, cash crops, and field crops for many years (Gan et al., 2008). This Appendix describes a specialized, unique mulching technique, known as Shatian gravel sand mulch.

The Shatian mulch and its adoption

In some marginal areas, such as some parts of the Loess Plateau that are theoretically not suitable for crop production in terms of quantity and timing of precipitation, farmers have survived for many generations by practicing a unique soil and water conservation system based on a gravel sand mulch. This system is known as Shatian. The technique can provide a satisfactory crop yield even in an arid climate of 200-300 mm annual precipitation (Chen et al., 2008). Chinese farmers have developed special field management techniques for this unique farming system for a wide range of crops. All kinds of vegetables, fruit trees, field crops can all be produced using the *Shatian* system (Fig. 2).

Fig. 2 Major crops and fruit trees growing in *Shatian*
(top, from left to right are: linseed, sweet pepper and water melon;
bottom, from left to right are apple, corn and wheat)

Shatian originated in Lanzhou, Gansu Province of China, but there is no consensus on the exact year of its development and use. However, it is normally accepted that *Shatian* was invented in very early times, but it became popular only 200 to 300 years ago, probably as a result of population pressures. Major distribution areas of *Shatian* are located in Lanzhou district of Gansu Province, and in the counties of Zhongwei, Haiyuan, Xingren and Zhongning of Ningxia, with a specific concentration in Gaolan and Baiyin county of Gansu and in the Xiangshan area of Zhongwei county of Ningxia.

Beneficial effects of Shatian gravel sand mulch

The most important impact of the system is conservation of soil water. The gravel or pebble mulch reduces surface water run-off, increases infiltration, and decreases evaporation. The mulch protects the soil surface against the effects of sun and wind, disrupts capillary rise of soil moisture, and reduces soil water evaporation, thus increasing available soil moisture. The gravel sand mulch protects the soil against runoff and wind erosion, and decreases salinity (Wang et al., 2003; Xie et al., 2003; Zhao et al., 2009).

Yang (2004) summarized data from past research and concluded that soil moisture in gravel sand mulched field is significantly higher than in the unmulched control, although effectiveness declines with time (Xu et al., 2009) . In addition, soil and air temperatures are 1-2℃ higher in spring and 3- 4℃ higher in summer than in unmulched soil (Gao, 1984). The date of frost penetration is delayed by 20 days or more, and the date of thaw is increased by about 15 days. The improved micro-environment is more favorable to plant growth, resulting in larger root systems, larger leaf area, higher photosynthesis and transpiration rates, earlier maturity (Xie et al., 2003), reduced incidence of insects, diseases and weeds (Zhao et al., 2009), higher yield and quality of produce, and higher soil moisture use efficiency (Xie et al., 2006; Yang, 2004).This extra growing window enables farmers to plant more exotic crops than normal (Lü & Chen, 1955), thus expanding their market potential. Furthermore, since gravels and pebbles contain selenium, there is sometimes higher selenium content in the produce.

Although the gravel sand mulch extends the cropping area into regions previously regarded as unsuitable, the productivity of *Shatian* declines with time (Wang et al., 2010). This is due mainly to declining soil fertility, and the mixing of soil particles with gravels and pebbles. Also, building new *Shatian* is extremely labor intensive. For these reasons, it is questionable how long this and similar systems will be used in the future, in view of the changing agricultural systems in China. However, the *Shatian* system is testimony to the enterprising and innovative spirit of farmers when faced with the major challenge of food production in challenging climates.

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