Conservation tillage research on the Loess Plateau of China

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Abstract
Conservation tillage was evaluated under local subsistence-orientated farming conditions found on the Loess Plateau of western China. Over six years, average wheat grain yield under an experimental no-tillage, stubble-retained treatment (NTS) was 18% higher (2.0 versus 1.7 t/ha) than under the traditional tillage and complete stubble removal treatment. The corresponding figures for field pea were 1.4 and 1.1 t/ha (20% increase). The main mechanism for higher grain yield under NTS was increased supply of soil water due to reduced soil evaporation and increased infiltration (reduced runoff). Soil quality was also improved and profitability under NTS was higher due to increased grain yield and decreased input costs (reduced labour due to no-tillage). Despite these significant benefits, the adoption of NTS systems in China remains low. The constraints to adoption, and future research and extension needs are discussed.

Key Words
No till; stubble retention; water use efficiency; grain yield; profitability; on-farm research

Introduction
The Loess Plateau of China has the unfortunate reputation of being one of the most eroded landscapes on earth. The soils and climate of the region contribute to the erosion problem but human factors such as high population density, poverty, overgrazing and excessive cultivation are important factors in the susceptibility of the land to severe erosion. In response to this situation, China and Australia commenced a bi-lateral research project into conservation tillage in 2000. For a more detailed description of the research see Huang et al.(2008). An analysis of the on-farm research methodology used in the project is provided by Whish et al. (2008). Hobbs (2007) provided a general review of conservation tillage and Li et al. (2007) have previously described the results from a long-term study in China. This paper provides an overview of the research that evaluated conservation tillage (no-tillage and stubble retention) methods, which have the potential to maintain or improve productivity while protecting and enhancing soil resources.

Climate, soils and farming systems
In China, the arid and semi-arid regions account for 52% of the land area. Rainfed farming systems predominate in China (Wei and Wang 1999) and on the Loess Plateau they occupy 80% of the total cultivated land area (Shan 1994). Most of the Loess Plateau is covered by deep loess soil dissected by eroded gullies. The sparse vegetation has a much lower proportion of forest coverage than the average of the whole country (Niu and Liu 2001). Most of the pasture land has been moderately or severely degraded in recent years (Ding 2001). The loess soils are deep, free-draining and able to store considerable plant-available water. However, a combination of low clay content and intensive cultivation results in low soil organic matter, structural instability (erosion) and low fertility for crop production (Zhu et al. 1983).

The Loess Plateau has a typical continental monsoonal climate, with most of the rain falling in summer and early autumn (June to September). Most of the area is 1000 to 2000 m above sea level. The duration of the summer cropping season is less than in North China but it is sufficient for successful annual mono-cropping. With the rise in topography from south-east to north-west, there is decreasing influence from the south-east monsoon, and a clear transition from a sub-humid to a semi-arid climate (Chen 1998, Gan et al. 2008). Rainfall varies greatly from year to year. The low annual rainfall (310-625 mm) cannot meet the potential crop requirement for water as determined by the productive capacity of light and temperature.

In the rainfed farming systems of the Loess Plateau, farms average just 1 ha in size and are operated by farming families. The farming systems are dominated by subsistence winter wheat in the more productive areas with higher rainfall, and subsistence spring wheat in less productive areas (Nolan et al. 2008). In higher rainfall areas, household grain consumption requirements are generally satisfied. Farmers are able to produce cash income from sale of produce. They have reinvested this income into their farms and developed new enterprises, particularly livestock, and co-operative trading arrangements. These developments have allowed many of these farmers to move away from subsistence grain production, so that most of households' cash income is now derived from both on-farm and off-farm sources. In lower rainfall areas, many farmers struggle to grow sufficient grain for their own use and generate very little cash income, often insufficient to provide basic needs such as education. Potatoes, peas, oilseeds, herbs and orchards are the most common cash crops here, and livestock enterprises are poorly developed. In this poorer area, cash income generated from on-farm activity is low; therefore, young male farmers often work off farm to support their families. With younger males gone, farms are often managed by elderly, women and children (Nolan et al. 2008).

The rainfed farming systems of the Loess Plateau are characterized by low-inputs for cropping systems. Farm manure is extensively applied in accordance with tradition. Chemical fertilisers are also applied at a rate of about 135 kg/ha (Liu and Chen 2005). Farmers rarely use pesticides or herbicides and rely primarily on conventional tillage practices and hand pulling to control weeds and pests. Only about 1/3 of sowing and harvesting is mechanical – animals, the principal source of draught-power, are very important for farmers.

Compared with farmers in lower rainfall areas, many more farmers in higher rainfall areas have intensive livestock production systems. In lower rainfall areas, almost all farmers have some livestock, such as cattle, donkey and pigs. Livestock are typically only sold in the case of crop failure or emergency. Cattle and donkey are used as draught animals, and pigs for household-consumption. Livestock feed consist of crop stubbles, forages (cut and carry), artificial rangeland from converting arable land in recent years, and grazing on roadsides and wastelands. However, in higher rainfall areas, maize and sorghum provide important feed for cattle, and grain crops and crop by-products are valuable for pig production (Nolan et al. 2008).

The problem that was addressed

On the Loess Plateau of China, soil erosion is particularly severe (Gan et al. 2008, Zhang et al. 2000), the highest in China (Liu 1999) and indeed amongst the highest in the world (Fu 1989). The severe erosion endangers food security, exacerbates poverty, and degrades soil and water resources, e.g. siltation of the Yellow River. Reasons for severe erosion are many, with traditional agriculture as being one of the most important man-made factors. Traditional crop production practice involves intensive cultivation – normally soil is ploughed three times and harrowed twice between harvest and spring sowing. The soil surface is bare during the 7-8 month-long fallow, which includes part of the rainy season. All stubbles and crop residues are removed out of the fields at crop harvest for use as livestock feed or as a source of energy for cooking and heating. In recent years, some areas of crop stubble are left standing (about 10 cm) since removing the crop stubble has a high opportunity cost under traditional management systems. All the traditional practices exacerbate degradation of soils, promote erosion and reduce production potential. Consequently, local farmers are trapped in a cycle of soil degradation and poverty.

The potential solution that was evaluated

These severe erosion and poverty problems have been recognised by Central and Provincial governments, which are now addressing rural poverty and environment issues across the Loess Plateau priorities (MOA 2001). In Gansu, Provincial strategies aim to reduce farmer reliance on grain production, increase the production of cash crops and livestock, and relocate farming villages to more fertile lands (MOA 2001, Feng et al. 2003). However, policy implementation has met with some local resistance on the western Loess Plateau, as the area has a tradition of crop cultivation several thousand years long. Local farmers are reluctant to convert their cropland to grass and forestry (Rui et al. 2002, Shi and Shao 2000, Zhang et al. 2004). Therefore, the development and demonstration of effective agronomic practice is needed to reduce erosion, increase crop productivity, ameliorate poverty and improve the environment.

Conservation tillage, developed in USA to combat soil loss and preserve soil moisture, represents the most dramatic change in soil management in modern agriculture (Bradford and Peterson 2000). In recent years, there has been increasing attention paid to conservation tillage around the world. The potential for conservation tillage to contribute to effective and sustainable use of soils is indisputable (Blevins and Frye 1993) and, as a result, conservation tillage can help improve food availability for the growing populations of many developing countries (Latin America, Asia, Africa) as highlighted previously by Derpsch (1998) and

Mrabet et al. (2001). Moreover, conservation tillage is attractive to farmers because of the potential for reduction of production costs compared to conventional tillage (Allmaras and Dowdy 1985).

Although sand mulch, direct sowing on standing stubble and bed systems in sloping land are part of what the Chinese called soil and water conservation, tillage has been a feature of agriculture in China for a long time. Modern conservation tillage only started research in China during the early 1980's. In 1992, China Agricultural University, in cooperation with the University of Queensland and Shanxi Farm Machinery Bureau, started conservation tillage trials in Shanxi Province (Gao and Li 2003). The results from this research showed that conservation tillage can help ease environmental problems, improve crop productivity and increase the sustainability of rain-fed agriculture (Huang 2003, Li 2006, Li et al. 2004, Li et al. 2005). Conservation tillage, integrated with cereal-legume crop rotation in semi-arid areas, has potential on the western Loess Plateau too. Although techniques such as no-till and stubble retention have achieved very good results under experimental conditions, adoption rates have been low due to the tradition of intensive cultivation.

The appropriateness of conservation tillage depends on a combination of biophysical and socio-economic factors and their interactions (Lal 1989, Lal 1991). The conservation tillage knowledge base developed in the USA, Canada and Australia is not directly transferable to the Loess Plateau, so there is a great need for systematic research into conservation tillage and its adoption locally. Hobbs (2007) highlighted the need for ongoing agronomic research to refine conservation tillage principles and tailor them for specific local environmental and socio-economic conditions.

Key results

In order to assess the applicability of conservation tillage methods under the soil, climate and farming conditions of the western Loess Plateau, an experiment on different conservation tillage systems was designed for a crop rotation of spring wheat and field pea, and implemented from August 2001 in Dingxi, a typical semi-arid area on the Loess Plateau. Six different tillage systems were included in the experiment: conventional tillage (T); no-till without stubble (NT); conventional tillage with stubble incorporated (TS); no-till with stubble retention (NTS); conventional tillage with plastic film mulch (TP) and no-till with plastic film mulch (NTP). Li (2006) and Huang et al. (2008) described in detail the conduct of the experiment. Only the results from the T and NTS treatments are discussed below, representing current traditional practice (T) and the most productive and sustainable treatment (NTS).

Grain yield under NTS was always greater than under T over a six year wheat-pea rotation

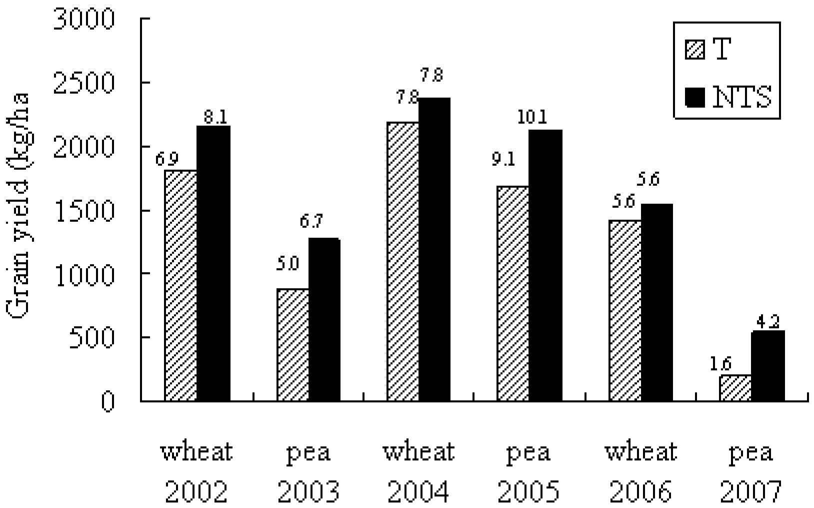

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Figure 1). The advantage of NTS was proportionally more in drier years (2003, 2007). Water use efficiency of wheat and pea under NTS was higher or equal to T, and again the advantage of NTS was greater in the drier years (2003, 2007). On average, grain yield under NTS was 18% higher than T for wheat (2.0 versus 1.7 t/ha) and 20% higher for pea (1.4 versus 1.1 t/ha).

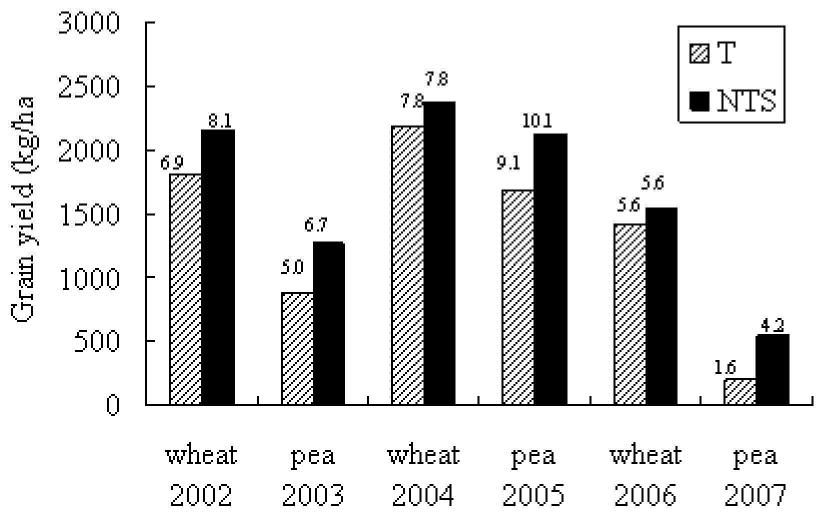

Figure 1. Grain yield of crops under traditional tillage (T) and No-till with stubble retention (NTS) (The numbers on the top of each column are water use efficiency in kg grain/ha/mm)

Surface soil water (0-10 cm) was higher under NTS compared to T, particularly during the critical spring sowing and crop establishment period. At other times, there was no significant difference between treatments in total soil water (0-200 cm). Soil bulk density was higher under no-tillage, and this was maintained in later years by no-till with straw cover compared to conventional tillage, conventional tillage with straw incorporated and no-till with no straw cover. Saturated hydraulic conductivity measurements indicated that no-till with straw cover can improve water infiltration significantly.

Stubble retained on the no-tilled soil surface did decrease soil temperature (0-25cm, measured at 14:00 h) in the wheat growing season, but this decrease in soil temperature did not delay or reduce wheat emergence, germination or crop yield.

Crops under NTS were more productive and yielded higher mainly because NTS improved water availability. No-till with stubble retention can reduce water losses from evaporation and runoff, and increase infiltration and availability of water to the crop.

Under a wheat-pea-wheat-pea-wheat-pea crop sequence, both total runoff and runoff intensity was reduced with NTS. Compared with T, runoff under NTS was reduced by 35%, infiltration increased by 39%, and runoff start time was delayed by almost four minutes. Soil loss from erosion was reduced by 62% and quantity of soil erosion reduced by 86%.

Profitability was improved greatly under no-till with stubble retention (Table 1). After 3 rotation cycles of spring wheat-field pea, average profitability of wheat and pea under NTS were 92% and 168% higher than that of T. The economic advantage of NTS was due to increased grain yield and reduced input costs (tillage). With time, profitability of crop production in this system can be expected to improve further with gradual improvements in soil fertility.

Table 1 Average profitability of crops across years (2002-2007) under different tillage practices (US$/ha)

Costs	wheat		pea	
	T	NTS	T	NTS
Costs[*1]	241	153	192	104
Income[*2]	392	442	262	292
Gross margin	151	289	70	187

[*1] Seed, fertiliser, herbicide, tillage
[*2] Grains only, converted by a price of USD 0.228/kg for both pea and wheat

Attempts to encourage adoption
In 2004, a program of on-farm research commenced in order to evaluate these promising experimental results under farmer-managed conditions. The on-farm research had multiple aims, to:

- extend research results from the main experimental site to farmer fields,
- engage farmers in thinking about and managing the change from traditional practice to conservation tillage,
- learn from farmers how they might adapt the experimental treatments to suit their own circumstances,
- discover problems experienced by farmers when implementing the experimental treatments on their farms, and
- collect data to allow simulation of the farmers' fields using a crop simulation model (APSIM).

The research design was a side-by-side comparison of traditional crop establishment systems with an experimental conservation tillage system (stubble retention and no tillage) and was repeated on 9 farms (Whish et al., 2008). Apart from the tillage and stubble treatments being compared, all other management were common across the two treatments that in reality were actually two different cropping systems.

The on-farm research confirmed the advantages of NTS found under experimental conditions, but the differences were not as large under the farmer-managed conditions. Several explanations are possible for this difference (Whish et al., 2008). A likely possibility is that farmers did not retain 100% of the crop stubble as was the practice in the main experiment.

To accelerate adoption of conservation tillage techniques, local government extension agencies such as the Dingxi Agricultural Technology Extension Center have been involved in both the experimental research and on-farm research. Partially as a result of the research conducted in this project, the Chinese Central government has initiated a 'National Key Technology R&D Program' into conservation tillage. The Gansu Agricultural University has received funding under this program for a new project, 'Integrated Research and Demonstration on Conservation tillage technology in Hilly and Gully Areas on the Loess Plateau'. Other related projects such as 'Research on conservation agriculture technology in inland irrigation areas', 'Research on mechanism of conservation tillage on sustainable improvement of soil quality', 'Demonstration and research of minimum/no-tillage in semi-arid areas' and 'Demonstration and research of key techniques of conservation agriculture in western erosion areas' have also received funding for research that builds on the original ACIAR research project.

Priorities for further research on conservation tillage in the area
Although no-till with stubble retention performed well compared with the traditional tillage practices as listed above, the adoption of the NTS approach has been very slow because of several obstacles. To accelerate adoption, further research and extension activities are needed on these obstacles, including:

- how farmer altitudes can be changed by demonstration and discussion,
- the availability and use of alternative fuels for cooking and feed for animals, to ensure enough stubble can be retained in the field,
- effective and environmental friendly herbicides to control weeds, and
- the reasons for differences between experimental and farm conditions in crop performance and response to treatments.

Capacity Building
With the implementation of this project, both Chinese and Australian researchers have benefited in terms of their personal and career development. Since the start of the project, more than 20 groups of Australian scientists have worked with Chinese scientists in agronomic field research, laboratory analysis, on-farm research, data collection and publishing scientific papers in international science journals. With help from Australian collaborators, one of our agri-chemical analytical laboratories was certified to ASPAC standards. Two scientific writing training workshops were run by Australians in Lanzhou in 2002 and 2003, and key researchers attended these workshops. Professor Huang Gaobao attended the Master Class of Agricultural Research Management with support from the Crawford Fund. Two researchers were trained in soil physics for 3 months at Wagga Wagga, especially in the use of a rainfall simulator and S theory (the relationship between soil physical quality and soil water retention curve), with support from the Crawford Fund. Six Chinese researchers attended national and international conferences in Australia, and four Chinese researchers were trained in APSIM modelling in Australia. Machinery and scientific equipment such as a no-till seeder,

automatic weather stations, rainfall simulator, penetrometer and other articles were provided as part of the ACIAR project, thereby improving our research capacity on conservation tillage. Eight Australian scientists were appointed as affiliate professors at Gansu Agricultural University. Four PhD students and eight Masters students completed their research thesis, supervised by Professor Huang Gaobao together with Australian scientists. Several Australian scientists also attended conferences in China. Based on this collaborative research, more 40 papers have been published in national and international journals.

Conclusions

On the Loess Plateau, severe soil erosion is a serious problem, endangering food security and resulting in poverty. Human activity, in particular traditional tillage practices have been one of the main contributing factors to this erosion. Based on more than six years of field research, an experimental no-till system with stubble retention treatment (NTS) has shown significant advantages in terms of crop growth and yield, soil temperature, soil water, WUE, soil physical properties, soil erosion and profitability.

Based on these and other encouraging results, the Chinese government has initiated large research and extension projects aimed at increasing the adoption of conservation tillage. Despite the attractiveness of conservation tillage, adoption rates remain low. Greater effort needs to be placed on understanding local constraints and modifying conservation tillage to better suit local conditions.

In addition to the specific research results, participation in this project has provided many tangible benefits to both Chinese and Australian scientists. These benefits include career progression, professional recognition through publication in international science journals, acquisition of new knowledge, skills and understanding, and access to new equipment and scientific approaches.

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