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Review

Developments in conservation tillage in rainfed regions of North China

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Abstract

Dryland regions in northern China account for over 50% of the nation's total area, where farming development is constrained by adverse weather, topography and water resource conditions, low fertility soils, and poor soil management. Conservation tillage research and application in dryland regions of northern China has been developed since the 1970s. Demonstration and extension of conservation tillage practices is actively stimulated by the Chinese government since 2002, following the recognition of the increased rate of degradation of the environment due to erosion and water shortage in North China. This paper reviews the research conducted on conservation tillage in dryland regions of northern China, and discusses the problems faced with the introduction and application of conservation tillage practices.

Most of the studies reported have shown positive results of soil and water conservation tillage practices. These practices generally involve a reduction in the number and intensity of operations compared to conventional tillage, with direct sowing or no-till as the strongest reduction. Crop yields and water use efficiency have increased (with up to 35%) following the implementation of reduced tillage practices. Under no-till, crop yields are equivalent to or higher than those from conventional tillage methods, especially in dry years. However, during wet years yields tend to be lower (10–15%) with no-till. Other benefits are an increased fallow water storage and reductions in water losses by evaporation. In order to fully exploit the advantages of conservation tillage, systems have to be adapted to regional characteristics. Farmers' adoption of conservation tillage is still limited.

Keywords: Conservation tillage; Residue management; Dryland farming; China; Technology adoption

Contents

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1. Introduction

Regions receiving between 250 and 600 mm of precipitation annually are considered to be dryland regions where dryland or rainfed-farming (crop production in low-rainfall areas without irrigation) is practiced (Xin and Wang, 1999). China has a large region of dryland in the north, which accounts for about 56% of the nation's total land area (Xin and Wang, 1999). Dryland farming in northern China is dominated by mono-cropping systems with mainly maize (*Zea mays* L.) and wheat (*Triticum aestivum*). Crop production in this dryland region is constrained by adverse weather, topography and water resource conditions (deep groundwater, very limited access to surface water), and low fertility soils under poor management. Conventional soil management practices include intensive soil cultivation, low fertilizer and manure inputs, and crop residue removal and burning. These practices have contributed to an exacerbation of soil, water and nutrient losses, and to degraded soils with low organic matter content and a fragile physical structure (Bi, 1995; Tang, 2004). This in turn has led to low crop yields and a low water and fertilizer use efficiency. The depletion of soil fertility and the decline in agricultural productivity in northern China have led scientists and policy makers to emphasize the need for the implementation of farming practices that contribute to the conservation of soil and water, with tillage as an important component of these practices (Wang, 1994; Lal, 2002).

The Chinese government is actively involved in the demonstration and extension of conservation tillage practices since 2002 (Zhang et al., 2004). This involvement was triggered by reports about the devastating eco-environmental degradation: topsoil loss, land degradation, air pollution, damage to trees, vegetation, buildings, transportation structures and waterways, and the deterioration of the living environment of human beings and livestock. This degradation was also shown by an increased frequency and intensity of dust storms, wind and water erosion and the loss of fertile top soil in northern China (Yang et al., 2001; Wang et al., 2004, 2006; Guo, 2004). The Chinese Ministry of Agriculture has formulated a plan for promoting a widespread application of conservation tillage throughout dryland regions of northern China within 7–10 years. Since 2002 about 60 demonstration counties within 13 provinces (municipalities and autonomous regions) of northern China, including Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Shandong, Henan, Shaanxi, Gansu, Ningxia, Qinghai, and Xinjiang were established (Rural Pastoral Area Mechanization, 2003). Demonstration areas covered 0.13 million ha in 2003 and are expected to reach 10 million ha in 2015. Notwithstanding these efforts, the present area under conservation tillage in China only accounts for 0.2% of the area worldwide where some form of no-till or conservation agriculture is applied (Bruinsma, 2003).

This paper reviews the research on conservation tillage in northern China and discusses the problems associated with the introduction and application of conservation tillage practices and their regional adaptation.

2. Site description and background information

2.1. Climate

Fig. 1 shows the dryland zones in northern China according to annual rainfall distribution pattern, based on INASR (1986). Five zones have been distinguished, i.e.: (1) arid (<250 mm); (2) arid semi-arid (250–350 mm); (3) semi-arid (350–500 mm); (4) dry semi-humid (500–600 mm); and (5) semi-humid (600–700 mm). Table 1 describes the characteristics and the dryland farming practices for each of these zones. The annual evapotranspiration ranges from 750 to 1080 mm, and the annual water deficit ranges from 40 to 740 mm (Table 2).

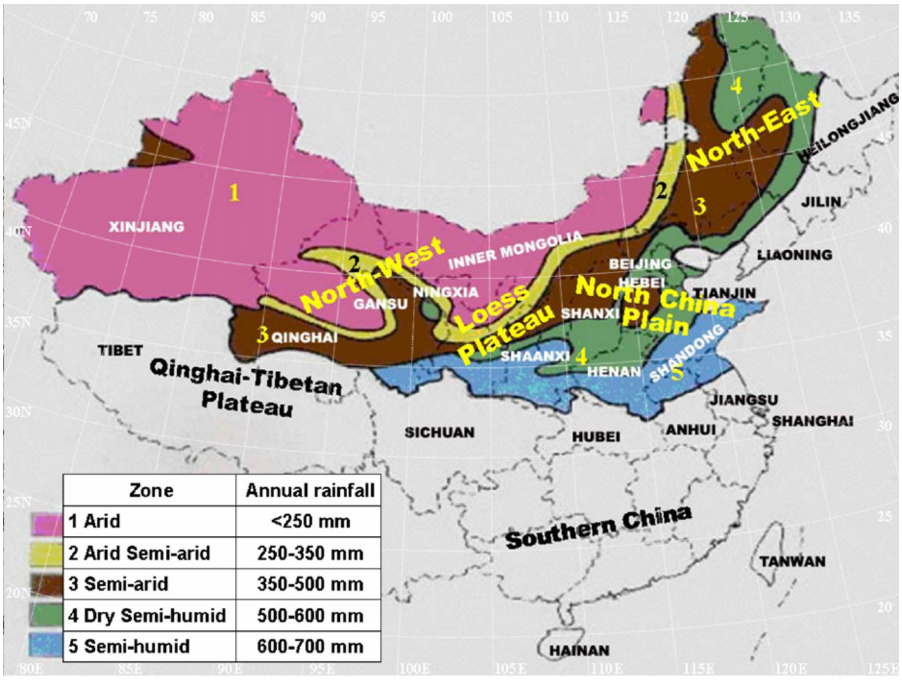

Fig. 1. Map of the climatic and agricultural zones in North China (modified from Xin and Wang, 1999).

2.2. Soil characteristics

The most important soil types are Desert soils and Aeolian soils in north-west, Loessial soils in the Loess Plateau, Dark-brown earths and Black soils in the north-east, and Cinnamon soils and Fluvo-aquic soils in the North China Plain region (soil classification based on ISS-CAS, 2003). The soils are neutral or alkaline with pH values ranging from 7.0 to 8.5, and with Ca and Mg as dominant exchangeable cations. On average, soil organic matter content is low (around 6–12 g kg^{-1}), due to a long farming history with intensive soil cultivation. Originally, soils are rich in K, but low in P. The range of available nutrients is 40–100 mg N kg^{-1}, 3–10 mg P kg^{-1}, and 70–150 mg K kg^{-1} (Bi, 1995). The total N content ranges from 0.6 to 1.0 g kg^{-1} and total P from 0.4 to 1.0 g kg^{-1}.

Severe water and wind erosion have caused the formation of a hilly landscape with a complicated topography. This is especially true in the northern regions, where the soils are mainly loess or loess-derived with steep slopes and with severe fertility limitations. Problems are prominent on land with eroded soil, land susceptible to drought, land with shallow soils, land with saline/sodic limitation, and desertified land. They account for approximately 58% up to 95% of the national problem soils (Fig. 2).

2.3. Crops

Rainfed crops grown in northern China include winter and spring wheat, maize, naked oat (*Avena nuda*), barley (*Hordeum vulgare*), potato (*Solanum tuberosum*), sorghum (*Sorghum* spp.), millet (*Panicum miliaceum*), soybean (*Glycine max*), pea (*Pisum sativum*), buckwheat (*Fagopyrum esculentum*), sunflower (*Helianthus annuus*), flax (*Linum usitatissimum*), rape (*Brassica napus*), cotton (*Gossypium herbaceum*), and tobacco (*Nicotinia tabacum*) (Wang, 1994). An indication of the evolution over time of the yields of dryland cereals is given in Fig. 3. Table 3 shows the area and the crop production volumes in three climatic zones. The percentage of arable land under irrigation in the different zones ranges from 16 to 39.

Table 4 describes the most common cropping systems in the dryland farming regions. The regional distribution of these systems is given in Table 1. Some shifting cultivation is practiced in hilly areas in some areas of north-west and north-east regions (Li, 2004).

2.4. Tillage and crop residue management practices

Traditional tillage in dry farming areas of northern China involves mouldboard ploughing (animal drawn or motorized) to a depth of 16–18 cm, followed by a

Table 1
Dryland farming zones and their regional characteristics of northern China (based on INASR, 1986; Xin and Zhang, 1987)

Climatic Zonification	Main agricultural regions (provinces covered)	Main soil types[a]	Rainfall/ dryness[b]	Temperature regime[c]	Cropping/livestock system[d]
Arid (zone 1)	North-west desert region (Xingjiang, inner Mongolian, part of Gansu, Ningxia, Qinghai)	Desert soils & Aeolian soils	<250 mm/yr; dryness > 3.5	0–10 °C mean/yr; sum 2000–4500 °C; 90–240 frost-free days	Animal husbandry; grazing; irrigated wheat and cotton; 1 crop/yr
Arid semi-arid (zone 2)	North-west windy–sandy region (eastern part of inner Mongolian, margin of desert in Gansu, Ningxia, and western part of NE)	Aeolian soils & Loessial soils	250–350 mm/yr; dryness 3.0–3.5	1–8 °C mean/yr; sum 2400–3800 °C; 100–160 frost-free days	Animal husbandry; grazing; rainfed spring wheat, millet, naked oats, potato; 1 crop/yr
Semi-arid (zone 3)	Loess Plateau hilly–gully region (most parts of Shaanxi, Shanxi, Gansu, Ningxia, Qinghai)	Loessial soils	350–500 mm/yr; dryness 1.6–3.0	4–10 °C mean/yr; sum 1500–4900 °C; 100–200 frost-free days	Extensive farming; arginal land use; rainfed spring wheat, spring maize, millet, sorghum, potato; 1 crop/yr
Dry semi-humid (zone 4)	North-east cold & North China Plain region (Jilin, Heilongjiang, Liaoning; Hebei, Henan, Beijing, Tianjin)	Dark-brown earths & Black soils; Cinnamon soils & Fluvo-aquic soils	500–600 mm/yr; dryness 1.3–1.6	−5–9 °C (NE)/8–15 °C; sum 3000–5200 °C; 100–240 frost-free days	Intensive tillage; rainfed winter wheat and spring maize; some irrigated; 1 crop/yr; 3 crop/2 yrs; 2 crop/yr
Semi-humid (zone 5)	North China Plain region (Shandong, part of Henan and Shaanxi)	Cinnamon soils & Fluvo-aquic soils	600–700 mm/yr; dryness 1.0–1.3	10–14 °C mean/yr; sum 2800–5200 °C; 120–210 frost-free days	Intensive farming; straw burning; irrigated winter wheat/summer maize; 3 crop/2 yrs; 2 crop/yr

[a] Soil classification based on ISS-CAS (2003).
[b] Dryness: ratio of annual evaporation to annual precipitation. Evaporation is calculated using open pan data.
[c] Annual temperature: sum of mean daily temperatures of frost-free days.
[d] Extensive farming: crop and animal production with low inputs on relatively large areas (>5 ha) of land; Intensive farming: crop and animal production with high inputs (fertilizer and—where possible—water) on small (<1 ha) areas of land.

sequence of harrowing, smoothing, rolling and hoeing. These operations are done with all crop residues removed, being used as fodder for animals or as fuel (Liu and Mou, 1988; Gao et al., 1991; Wang, 1994). Burning crop residue has increased during the last decades (Wang et al., 1999).

Tractors have steadily replaced draft animals since 1970. As an example, a survey in the village Zongai (with 400 ha farmland) of Shouyang in Shanxi province (the dry semi-humid zone) showed that the number of tractors, increased from one tractor in 1973, to four tractors in 1983, and 28 tractors in 1993. Data from all of China show a 75-fold increase in tractor numbers from 1970 to 2003 (Li, 2005).

Intensive ploughing has contributed to increasing risks of soil erosion by wind and water, but also to soil compaction and the formation of a hard pan in the subsoil layer (Cai and Wang, 2002; Gao et al., 1991). It has also resulted in soil organic matter depletion, reducing soil structural stability, soil fertility, and soil water retention (Cai et al., 1994, 1995). Traditional farming methods require high inputs of energy and labour that are about 60–70% higher than for reduced tillage practices (Wang et al., 2003b).

2.5. Nutrient management

In China, fertilizer is the most costly input in crop production. In 1990/1991, mean fertilizer cost in China accounted 25% of the total expenses for agricultural production (cost of input material plus labour), and 50% of total cost for input materials (cost for seed, fertilizer, pesticide, machinery, irrigation) (Lin et al., 1999). Although fertilizer use has greatly increased, most of it is applied on fertile soils in the lowland and the developed areas. Little or no fertilizer is applied in

Table 2
Annual potential evapotranspiration (ET_0) and water deficit in dryland regions of northern China (1951–987) (modified from Leng and Han, 1996)

City, province	Climatic zone	ET_0 (mm/yr)	Water deficit (mm/yr)
Urumqui, Xinjiang	1	970	−593
Yinchuan, Ningxia	1	1079	−742
Lanzhou, Gansu	1	908	−540
Yuzhong, Gansu	2	986	−562
Haiyuan, Ningxia	2	1156	−753
Huhehaote, Inner Mongolia	3	870	−435
Xining, Qinhai	3	874	−527
Shijiazhuang, Hebei	3	905	−355
Datong, Shanxi	3	877	−493
Taiyuan, Shanxi	3	852	−414
Xian, Shaanxi	4	794	−233
Beijing	4	927	−283
Changchun, Jilin	4	830	−237
Harbin, Heilongjiang	4	791	−273
Shenyang, Liaoning	5	749	−39

ET_0 is estimated using FAO modified Penman equation by Frère and Popov (1979), Data for climatic zone 2 are based on Yan et al. (2002).

much of the land in hilly areas with shifting cultivation practices, especially in the poor areas of the Loess Plateau region. The use of fertilizer in dry farming areas of northern China is less than half of the mean national fertilizer use (which was 235 kg ha^{-1} in 1998; FAO, 1999). The average fertilizer input in 1995 (in kg ha^{-1}) was 169 in zone 1 (Table 1), 28 in zone 2, 124 in zone 3, 223 in zone 4, and 238 in zone 5 (Xin et al., 2002). The survey in Zongai village provides an indication of the trend in fertilizer use in the dry semi-humid zone of northern China during the period 1963–1999. Before the 1970s farmyard manure was the main source of nutrients applied. Fertilizer use increased until the 1990s, and has been maintained since at levels of approximately 130 kg N and 25 kg P per hectare (Wang et al., 1999),

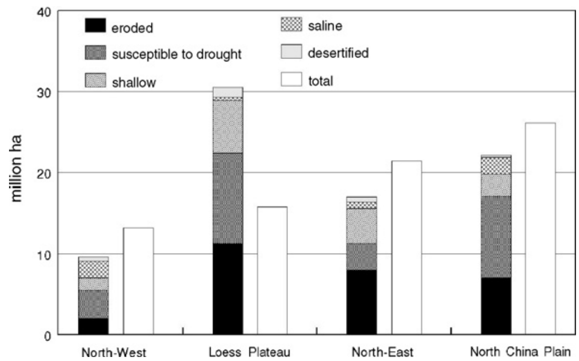

Fig. 2. Main problem soils in the dryland regions of North China (modified and recalculated from Bi, 1995). Soils may be associated with more than one problem.

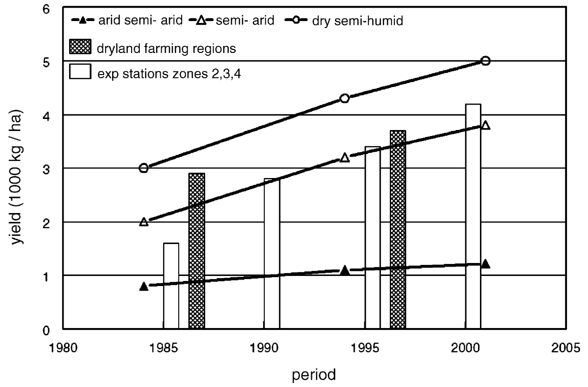

Fig. 3. Trends in cereal yields in the dryland zones of North China. Data based on Wang (1994), and Xin et al. (2002).

with a ratio of N:P, 1:0.2. This ratio of N to P is higher than the recommended ratio of 1:0.3 for dryland. Use of animal manure did not increase during the last years, because of the slow development of animal production. The average amount of animal manure applied was 4875 kg ha^{-1} (about 2715 kg ha^{-1} in dry weight), equivalent to 26 kg N, 4.8 kg P and 20 kg K (based on the nutrient contents of local cattle manure) (Wang et al., 1999). These data follow the trends shown for all of China by Tong. et al. (2003), but remain at a lower level.

Fertilizer use efficiency, nutrient recovery, and yield responses to fertilizers are low. This is caused by poor nutrient management, such as using inappropriate fertilizer sources, application methods, and unbalanced ratios of N:P:K. Nutrient losses by soil erosion are high (Wang, 1994; Lin et al., 1999). Ammonium bicarbonate $(NH_4)HCO_3$ has been used as a main source of N fertilizer, which has higher NH_3 volatilization and lower use efficiency than urea fertilizer (Lu and Shi, 1982). Surface application under dry soil conditions increases risks of N loss by NH_3 volatilization and by soil erosion (Wang et al., 2003c; Cai et al., 2002).

3. Problems encountered with conventional tillage systems

Crop production in dryland farming is influenced by a multitude of factors ranging from climate to economy (Liu and Mou, 1988; Tao et al., 1993). The increasing population results in an increased demand for food, thus putting pressure on the land and forces farmers to increase land use intensity (Bi, 1995). The intensification of crop production contributes to a range of negative environmental effects: clean-tilled soils, unprotected for extended periods during drought, lead to land salinity and infertility and to wind erosion with an increased frequency and intensity of sandstorms (Tang, 2004;

Table 3
Crop production in dryland farming zones of northern China (modified and recalculated from Tao et al., 1993; Xin and Wang, 1999)

Climatic zone (reference Table 1)	Population (million)	Total area (million ha)	Arable land (million ha)	% Irrigated	Total cereals (million tonnes)	Yield (1000 kg/ha)
2	6.5	13.1	1.8	16.3	1.9	1.1
3	93.0	74.6	15.8	29.7	51.1	3.2
4	130.0	35.0	15.3	38.7	65.8	4.3
Total China	1184.7		94.9	52.0	466.6	4.9
% of total China	19.4		34.7		25.5	

Yang et al., 2001; Wang, 2000; Wang et al., 2003). The resulting soil degradation has led to a reduction of productivity and to poverty (Tang, 2004; Yang et al., 2001). Most provinces of northern China face serious poverty problems related to poor land use management. Provinces in the north-west and the Loess Plateau remain economically the most underdeveloped regions in China, as indicated by their low ranking of Gross Domestic Product (among the nation's 31 provinces, the provinces Ningxia, Qinghai, Inner Mongolia, Gansu, Shanxi, and Shaanxi rank 30, 29, 24, 27, 22, and 21, respectively) (National Bureau of Statistics of China, 1999, 2003).

4. Conservation tillage practices: application and research

4.1. Indigenous conservation farming practices

Local farmers have experience in using methods to alleviate the effects of drought on crop production in the dryland farming regions of northern China (Liu and Mou, 1988; Xin et al., 2002; Li, 2004). These traditional methods include reduced tillage and no-till practices, and are known as '*sand covering cultivation*' in the north-west, '*furrow-seeding or square-pit methods*' in the Loess Plateau, '*ridge cultivation*' in the north-east regions, and '*direct sowing in the stubble field*' in the North China Plain. A brief description of these methods is given in Table 5. Most of the systems are very labour-intensive.

4.2. Developments in conservation tillage research

Since the 1970s soil tillage systems have changed greatly following the development and introduction of mechanized farming technologies. Research on reduced tillage and no-till systems in China was initiated in that period (Liu and Mou, 1988). The aim of the research was to develop new dryland farming technologies and to improve the traditional practices (Table 5) with advanced technology. These improved practices (Liu and Mou, 1988; Wang, 1994; Xin et al., 2002) are listed in Table 6. Tillage intensity or number of passes is reduced, and although individual operations may not use less energy, the total production costs are lower than conventional practices due to a reduced number of operations, less labour and a lower machinery input (Li et al., 2005).

Table 4
Cropping systems of the dryland farming regions

Cropping system	Crops[a]	Seasonal distribution
Single	Wheat, maize, millet, sorghum, potato	Wheat will be grown as winter wheat (sown in autumn), temperature permitting. Otherwise wheat is grown as summer crop (sown in spring), as are all other crops listed. Maize is preferred as summer crop (sown in spring), millet and sorghum are sown when water availability is too low
Three crops in 2 years	Maize (s), sorghum (s), millet (s), sweet potato (s), wheat (w)	One of the (s) crops sown early spring of year 1, followed by wheat sown in autumn of year 1, followed by (s) again in year 2, but now sown late spring – early summer. Autumn and winter of year 2 is fallow
Two crops per year	Wheat, maize	Wheat is grown in winter (autumn sown) followed by maize grown in summer (spring sown)

[a] Annual and perennial intercropping is practiced locally: maize with legumes/potato, cereals with forage grass/legumes, and relay intercropping of cereals with potato/forage grass.

Table 5
Indigenous conservation farming systems in dryland regions of northern China (based on Liu and Mou, 1988; Xin et al., 2002; Li, 2004)

Region	Description of indigenous conservation farming systems	Utilization and effects
North-west region (mainly in Gansu)	Sand covering no-till cultivation: small fields are covered with a layer (10–15 cm) of gravelly sand, graded from coarse at the bottom to fine near the surface. Organic fertilizers are sprayed on top, sowing without seedbed preparation with a thin (1–2 cm) covering of sand.	For spring wheat, millet, potato crop cultivation: yield up 1–2 times; water infiltration up 9 times; water content up 4–12%; salinization down 51–89%; soil temperature up 1–2 °C; crop maturity for fall and summer harvest 20–30 days and 7–10 days earlier compared to uncovered fields
	Rainwater-harvesting: collection of rainwater from the compacted surfaces or rocks, paved courtyard, rooftops. Storage in an underground cellar or kiln with capacity of 30–50 m^3	Supplemental irrigation leads to higher yields of wheat, maize, and cotton (up by 20–40%) and allows production of cash crops
Loess Plateau region (mainly in Shaanxi and Shanxi)	Furrow-seeding or square-pit sowing methods: square-pits of 15–20 cm depth and 20–30 cm width are dug on terraced or sloping land in hilly areas, organic fertilizers are applied in the pits before sowing	For maize, wheat, sorghum, millet, potato, and soybeans, yields increase by 30%
North-east region (mainly in Heilongjiang, Jilin, and Liaoning)	Ridge cultivation combined with subsoiling between rows: building ridges 15–20 cm high and 25–30 wide; subsoiling 30–40 depth at 60–120 cm intervals	Soybean–sorghum–millet rotation: main tillage only once in a 3-year rotation;
	Tillage in a 2–3 year rotation and harrowing: sowing after harrowing (2–4 times) at 10–15 cm depth, subsoiling every 2–3 years	(1) Wheat–coarse cereals–soybean rotation: fall ploughing for wheat, fall harrowing for coarse cereals, fall harrowing for soybean
	Reduced tillage by skipping tillage operations: depending on the field condition, main tillage operation between two crops will be skipped, sometimes compensated for by additional fertilization	(2) Sorghum–soybean–maize–maize rotation: fall ploughing for sorghum–fall harrowing for soybean–fall ploughing for maize (2×)
North China Plain region (mainly in Beijing and Hebei)	Direct sowing in stubble: leaving stubble 25–30 cm high, and sowing at 60 cm width for maize; 20 cm width for wheat	For summer sown crop immediately after previous crop harvest, e.g. in winter wheat–summer maize rotation cropping system

Table 6
Improved tillage practices

Improved practices	Description
No-till	For all cereal crops, keeping stubble and straw/stalks as a mulch on the surface after harvest in summer or autumn. Sowing with a no-till planter combined with banded fertilizer application
Subsoiling with straw mulching[a]	For winter wheat, keeping stubble (25–30 cm) and straw as a mulch on the surface after harvest in summer; subsoiling to 30–35 cm depth, distance between shanks approximately 60 cm; sowing without seedbed preparation combined with fertilizer application in autumn
Ploughing with crop residue incorporation	For spring maize, incorporating straw and fertilizers by deep ploughing (25–28 cm depth) after harvest in autumn; no seedbed preparation before sowing with a no-till planter combined with banded fertilizer application in spring
Furrow sowing	Square-pits 15–20 cm deep and 20–30 wide are made on terraced or sloping land in hilly areas. Organic fertilizers are applied in the pits before sowing
Ridge-ditch subsoiling	Fields are subsoiled to 30–40 depth at 60–120 cm intervals every 2–3 years; ridges 15–20 cm high and 25–30 width are built in between the subsoiled lines. Crops are grown on top of the ridges.
Stubble disking	Crop stubble remains on the field. No ploughing, seedbed preparation with a disk harrow (10–15 cm depth) immediately before sowing

[a] Also called as reduced tillage with subsoiling, or interval subsoiling.

Table 7a
Research projects on conservation tillage in rainfed regions of northern China

Number	Location & crop	Project (year)	Reference
1	Tunliu, Shanxi, winter wheat	The National 7th 5-year project (1986–1990)	Gao et al. (1991)
2	Linfen, Shanxi, winter wheat	The National 8th 5-year project (1991–1995)	Cai et al. (1995), Wang and Cai (2000)
3	Linfen, Shanxi, winter wheat	Sino-Australia project (1992–2003)	Du et al. (2000), Li et al. (1997, 2000), Gao et al. (2003)
4	Luoyang, Henan, winter wheat	Sino-Belgium program (1998–2003)	Cai et al. (2002), Cornelis et al. (2002), Schiettecatte et al. (2002), Wang et al. (2003b)
5	Tunliu, Shanxi, spring maize	The National 7th 5-year project (1986–1990)	Gao et al. (1990), Wang et al. (2003a)
6	Shouyang, Shanxi, spring maize	The National 8th/10th 5-year project (1991–1995/2001–2005)	Cai et al. (2002), Wang and Cai (2005)
7	Shouyang, Shanxi, spring maize	The National 8th–10th 5-year project (1991–2005)	Wang et al. (2003c, 2005)
8	Hebei, summer maize–winter wheat	Sino-Canada project (1991–2003)	Sun et al. (1995), Zhang et al. (2000), Jia et al. (2003), Ren et al. (2003)
9	Yangling, Shaanxi, summer maize –winter wheat	Shaanxi Province (2001–2003)	Yang et al. (2004)
10	Daxing, Beijing, summer maize	Sino-EU project (1995–1997)	Ding and Hann (2000), Xu and Mermoud (2001)

Since the 1980s, a series of research projects on dryland farming, initiated by the Chinese Academy of Agricultural Sciences (CAAS), have been carried out in northern China. Studies on conservation tillage methods have been conducted in Shanxi in the dry semi-humid region. During 1980–1985 studies on the effects of different tillage methods on soil physical condition, soil water storage and single rainfed wheat and rainfed maize production were conducted in Tunliu (Shanxi province). During 1986–1990, the research in Tunliu focussed on the effects of alternative tillage techniques for soil water conservation. Tillage methods were developed that combined subsoiling (to break the hard pan) with mulching of straw during the summer (rainy season) fallow for rainfed wheat production, and surface residue application for rainfed maize production (Gao et al., 1990, 1991; Wang et al., 1995). During 1990–1995, studies on conservation tillage in combination with farm machinery use and agronomy in dryland farming were conducted in Linfen and Shouyang in Shanxi province (Cai et al., 1994, 1995). Compared with conventional tillage, spring maize seedling emergence was 2–3 days earlier and 17–23% higher in a dry spring but the benefit of conservation tillage was much less in a relatively wet year (Cai and Wang, 2002). The results led to recommending two sets of conservation tillage systems for spring maize in dryland areas: (1) subsoiling between rows or no-till with whole maize stalk mulching after fall harvest, and direct seeding the following spring; (2) deep ploughing with incorporated straw and fertilizers after harvest in the fall, and direct seeding of maize in spring (Table 6). The two sets of conservation tillage systems have shown promising results in terms of reducing water losses and soil erosion, saving energy, increasing maize yield, and improving water use efficiency (WUE). Since the 1990s long-term field experiments on the effects of reduced tillage and residue management on nutrient cycling are being conducted in dryland farming systems in Shouyang. The results of these experiments have shown that application of crop residue was of benefit to soil protection, water conservation, soil fertility build-up, and crop yield increase (Wang et al., 2001, 2003a; Wang and Cai, 2002). However, under different weather conditions, tillage and residue management methods result in different effects. For example, straw mulching was suitable for water conservation and resulted in a yield increase in the dryland areas (such as for winter wheat in Tunliu and Linfen of Shanxi) where the annual average temperature is above 9 °C. Straw incorporation, however, out competed straw mulching, in terms of improvements of water and nutrient availability, and crop yield, in those areas where the annual average temperature is low, around 7 °C, as was found for spring maize in Shouyang (Wang and Cai, 2000). The surface temperature under mulch during seedling period decreased by 2–6 °C, as compared with stubble removed or incorporated (Cai et al., 2002). A study simulating soil organic carbon dynamics suggested that with conservation tillage practices on

Table 7b
Summary of research findings from conservation tillage research (in comparison to conventional tillage) in rainfed regions of northern China

Number	Fallow water storage	Yield effects	WUE	ET	Other benefit
1	49% with DP	Up 13–22% with DP		Up 3–18% with DP	
2	40–49% with SS; 15% with NT	Up 12–14% with NT/SS; up 15–33% with RM; down 5–6% with NT/SS (1994)	Up 2–27% with NT/SS	Down 9–11% with NT/SS	
3		Up 18.5% with NT/SS	Up 19% with NT/SS		Runoff & wind erosion: down 60% with NT/SS
4	3–16% with NT; 2–12% with SS	Up 8–9% with SS; up 5% with NT (2001); down 9% with NT (2000)		Up 1–13% with NT/SS	Total cost: down 93% with NT; down 58% with SS
5		Up 2–21% with DP + RI; up 17–21% with RM; down 5–14% with NT	Up 1–20% with DP + RI; up 15–18% with RM	Up 2% with DP + RI	
6	3–15% with DP + RI; 6–13% with NT/SS	Up 11–35% with DP + RI; up 4–22% with NT/SS; down 11–14% with NT/SS (1995, wet)	Up 29–36% with DP + RI; up 10–32% with NT/SS	Down 2–7% with DP + RI; down 4–10% with NT/SS	Wind erosion: down 60–68% with DP/SS; down 79% with NT
7		Up 17% with RI (11 year average)	Up 23% with RI (11 year average)		SOM: up 1.2% with RI (11 year average)
8		Up 10–15% with NT maize; no diff. with NT wheat, down 30% after 3 years			SOM: up 1.37%, 1.47%, 1.80% with NT wheat (2000, 2001, 2002) annually
9		Up 53% with NT wheat; up 25% with NT corn			
10		Up 11%–29% with RM; up 11–20% with SS; no diff. with NT	Up 46% with RM; up 19% with SS	Down 17% with RM; down 12% with SS	

Note: WUE: water use efficiency; ET: evapo(transpi)ration; NT: no-till; DP: deep ploughing; SS: subsoiling; RI: residue incorporated; RM: straw mulching.

average at least 50% of the crop residue should be returned in the soil to maintain acceptable organic carbon levels. This study was based on data from 10 years of field experiments with residue, manure and fertilizer application in dryland maize production systems (Wang et al., 2005).

Other research projects on conservation tillage are underway in Hebei (Zhou et al., 2001), Qinghai (Chen et al., 2004), Shanxi (Xu et al., 2001; Wang and Wang, 1995; Min et al., 2001; Yang et al., 2004). Long-term experiments have also been carried out in international cooperative projects.

The results of these and the most important national projects are summarized in Tables 7a and 7b. Conservation tillage increases soil water storage (from 3 up to 50%), reduces wind erosion, increases crop yields (from 8 to 35%) and water use efficiencies (2–36%), saves energy and reduces labour inputs (with more than 60%), as compared to conventional tillage. Yields under no-till are equivalent to those under conventional tillage in years with an average rainfall pattern, higher in dry years (from 4 to 22%), and usually lower during wet years.

4.3. Regional adaptation of conservation tillage systems

The slow acceptance and adoption of conservation tillage practices may be attributed to several factors, associated with conceptual, scientific, and technological reasons. Faced with the immense pressure of human and animal population increases and a limited agricultural land base, Chinese governmental institutions and Chinese farmers have placed a high priority on food production and food security rather than on environmental protection and conservation of natural resources, with sometimes disastrous results. In northern China in particular, conservation tillage practices have to be adapted to site characteristics: climate, soil type, terrain, cropping system, and other land use at the farm. Therefore, conservation tillage system options are grouped according to four dryland zones, as shown in

Table 8
Regional options of conservation tillage systems (including tillage-related management practices of residue, fertilizer, crop rotation, water and pesticide) in northern China

Zone	Characteristics and problems	Conservation tillage system	Additional conservation measures
North-west desert	Serious wind erosion Desertification Land degradation Cold winter	No-till fallow/subsoiling Keeping stubble/cover crops No-till sowing Adding organic/inorganic fertilizers	Windbreaks and shelterbelts
Loess plateau	Serious water erosion Drought Deforestation Infertile land	Growing cover crops Stubble surface cover No-till sowing	Terracing/contour/strip cropping Agroforestry (alley cropping)
North-east cold region	Short frost-free period Serious spring drought Water/wind erosion Soil degradation/compaction	Reduced till/ridge-till Crop rotations Keeping high stubble cover No-till sowing Adding organic manure	
North China Plain region	Spring drought Summer flood Secondary salinization Water pollution	Crop residue conservation No-till sowing in mulch Balanced fertilizer application Weed control with herbicides	Water-saving irrigation practices

Table 8 (Ministry of Agriculture of China, 2003; Gao et al., 2003). Each option attempts to integrate the components: post-harvest tillage, residue management, sowing techniques (machinery) and weed/pest management.

5. Conclusions

Chinese researchers are developing better dryland farming technologies for northern China by introducing new soil conservation practices and improving traditional "drought-resisting" practices with advanced technology. Since the 1980s, research efforts on conservation tillage have expanded via a large number of national and international research projects. The Chinese government, recognizing the environmental impacts of sand and dust storms, wind erosion, water erosion, and land degradation, actively promotes the application of conservation tillage practices.

The use of reduced tillage practices has shown promising results. Compared to conventional tillage, these practices have shown to increase water storage, reduce water loss and wind erosion, to improve crop yield and water use efficiency, and to save energy and labour inputs. Under no-till, mean crop yields are equivalent to those under conventional till. In dry years, crop yields tend to be higher and in wet years lower with no-till compared to conventional till. Lower crop yields with no-till in wet years have been related to a decreased soil temperature and seedling emergence.

Notwithstanding the research achievements and the promotional activities of the government, traditional cultivation with intensive ploughing and residue removal or burning, is still common practice, and considerable efforts will have to be made to accomplish widespread application of conservation tillage.

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