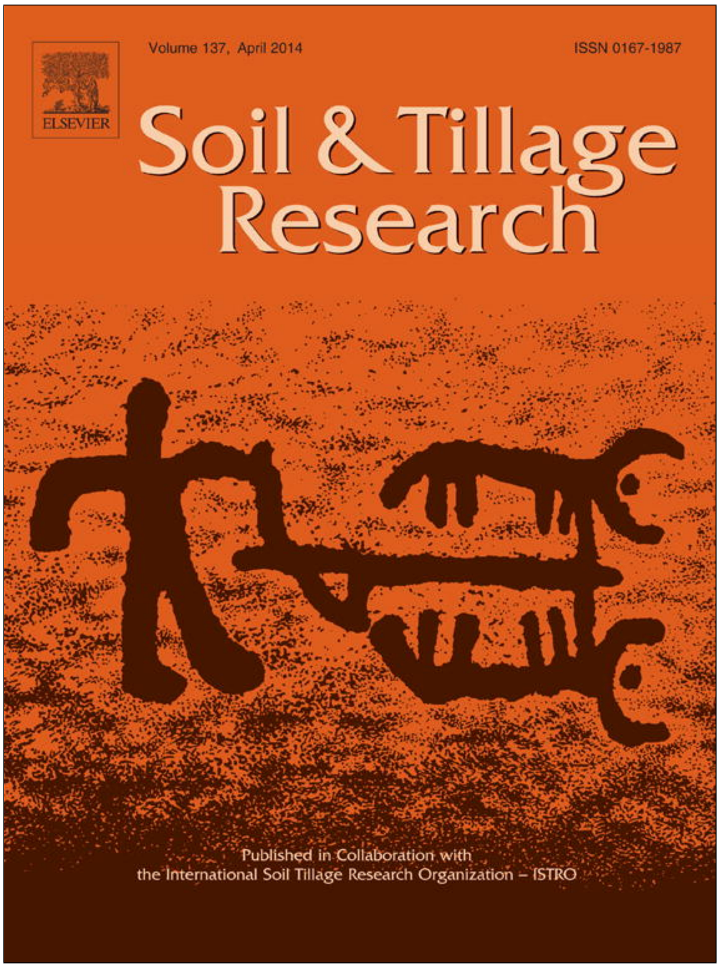
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The effects of no-tillage with subsoiling on soil properties and maize yield: 12-Year experiment on alkaline soils of Northeast China

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ABSTRACT

Soil sodicity and salinization are two major issues concerning agricultural production in Northern China and the affected areas are expanding at a rate of 1–1.5 Mha/year. The effects of two treatments, i.e. no-tillage with subsoiling and straw cover (NTSC) and conventional tillage with ploughing and straw removal (CTSR), on soil physical and chemical properties and yields were compared from 1999 to 2011. The results showed that NTSC reduced soil bulk density in the 0–30 cm soil layer, but more importantly the treatment increased total porosity by 20.9%, water stable aggregates and pore size class distribution. The enhance soil structure and improved infiltration in NTSC treatments contributed to reducing soil salinity by 20.3%–73.4% when compared with CTSR. Soil organic matter was significantly greater to 30 cm in NTSC, while total soil nitrogen was lower than CTSR treatments; however, available P was significantly higher in the 0–5 cm soil surface. During the first 3 years, there was no difference in spring maize yield between NTSC and CTSR, but yield significantly increased in NTSC compared with CTSR during the remaining years due to reduced salinity stress and increased soil health. In conclusion, NTSC soil management practices appear to be a more sustainable approach to farming than conventional methods that utilize intensive tillage and crop residue removal.

1. Introduction

Soil sodicity and salinization are two major issues concerning agricultural production in Northern China. Saline soils are generally confined to 5 areas, these are; the Coastal Saline Soil Area, the Huanghuaihai Plain Saline Soil Area, the Northwest Semi-arid Saline Soil Area, the Northwest Arid Saline Soil Area, and the Northeast Saline Soil Area. In the Coastal Saline Soil Area, the main cause of soil salinity is salt water intrusion from rivers and ocean. In the other areas soil salinity is caused by drought conditions, generally low rainfall, high evaporation rates and inappropriate land management. According to the National Land and Resources Survey conducted by the Chinese Ministry of Land and Resources, about 9.54 million hectares of the total land area is saline (MLR, 2005). However this is not static and according to Huang et al. (2006) soil salinization is increasing at a rate of 1–1.5 Mha/year. In north eastern China, spring maize is one of the most important grain crops with a cultivated area of 6.54 Mha. Annual yield is 42.5 Mt, which is around 20% of the total national area and 31.2% of the total national maize yield (Liu et al., 2002). Agricultural mechanization and persistent intensive tillage over a number of decades has degraded the soil structure, increased soil salinity, and reduced soil fertility (Niu and Wang, 2002). High salt concentrations in the soil limits agricultural production by impeding plant nutrient uptake, inducing physiological stress and predisposes the plants to diseases and pest attack (Li et al., 2006). Remediation approaches adopted so far in order to deal with the problem of soil salinity mainly focuses on soil chemical and biological measures. For instance, Wang et al. (1994) reported that planting the cereal grass, *Eragrostis pilosa* for three years in a saline soil could improve the soil structure. Other researchers investigated soil salinity reduction with the use of polymers and the effect on soil structure and crop growth (Kazanskii and Dubrovskii, 1992; Bicerano, 1994; Gong et al., 2009). In addition, researchers have studied the positive effect of wide range of salt tolerant to halophytic coastline trees and shrubs i.e. *Casuarina equisetifolia*, *Populus euphratica*, *Hippophae rhamnoides*, *Malus zumi*, *Elaeagnus angustifolia*, *Suaeda glauca*, *Salicornia bigelovii*, etc., on soil salinity. However, most of

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the above biological methods require years to improve soil structure and soil fertility. Furthermore, fields cannot be planted with staple crops for a considerable time, therefore limiting the commercial value (staple food production) of such remedial methods.

The alternative, according to Li et al. (2006) is to adopt a physical soil management approach and they showed that precise land leveling, deep ploughing, effective water drainage and field residue cover can improve saline soil conditions. On the basis of this and previous research, conservation tillage and soil cover has been proven to be an effective method to improve soil structure and fertility, while reducing soil water evaporation (Li et al., 2007), and soil salinity (Li et al., 2010). Ma et al. (2010) demonstrated that residue cover decreased soil water evaporation rate and hindered salt accumulation on the soil surface. Additionally the plant roots from remaining stubble can improve soil capillarity, enhance water infiltration and supplement the leaching of salts from the root zone. Zhang (1995) indicated that other physical approaches such as subsoiling can increase soil water infiltration and salt leaching. The addition of straw cover increased soil water content promoted salt leaching, and prevented increases in soil salinity, with potential yield increases of 2.5%–14.6%. Similar remediation studies conducted by Xi et al. (2003) In the Yellow River Delta prevented salinity levels from increasing, improved soil structure, increased soil organic matter and soil fertility.

In other countries, conservation tillage has been shown to improve soil structure, soil fertiliser use and corn yield (Aase and Pikul, 1995; CTIC, 1995; Ronald, 1997); however, there are several factors that may contribute to the improvement in soil condition when tillage is reduced. For example on a saline soil in semi-arid subtropical climate, an eight-year application of conservation tillage improved the concentration of organic C and N (Zibilske et al., 2002).

Although several domestic and International studies have shown that conservation tillage can improve soil physical properties and increase soil fertility, there is limited information on soil management options for saline soils in the rain fed areas of Northeast China. The application of conservation tillage to highly saline cultivation areas in China is poorly understood and the longer term effects of no-tillage with subsoiling and straw management practices on SOM, nutrients, soil physical properties and crop yields are equally unknown.

The objective of this research was to demonstrate that no-tillage with subsoiling and straw cover (NTSC) reduces salinity accumulation and improves soil structure and crop yield, when compared with conventional tillage and straw removal (CTSR).

2. Materials and methods

2.1. Site description

A long-term study (1999–2011) was conducted in Liaoning province (NE China), which has a temperate continental climate with four distinct seasons. Mean annual temperature in the region is 8.71 °C, with a frost-free period of around 150 days. Rainfall is widely variable across the different seasons, however 70% of the annual precipitation occurs during June to August (Summer) with an annual average of 421 mm (Fig. 1). Typically, a single spring maize crop is grown each year, which is sown in mid-April and harvested in late September or early October.

The experimental site was located in Paozi County near Funxin City (42°12 N, 122°20 E) which is 248 m above sea level, consisting of a soil type classified as a Chromic Cambisol under the FAO/UNESCO soil classification system (FAO/UNESCO, 1974). This alkaline soil had a particle size distribution of sand 25.7%, silt 45.1%, clay 29.2%, with an average profile alkalinity of pH8.9 and salt content of 2.73% at 0–30 cm depth. Extensive soil degradation was found across the site to a depth of 30 cm, as evidenced by an average bulk density of 1.6 g/m^3 and the large uneven clods that dominated the field. Intensive deep ploughing and leveling was undertaken to prepare the site for the experiment.

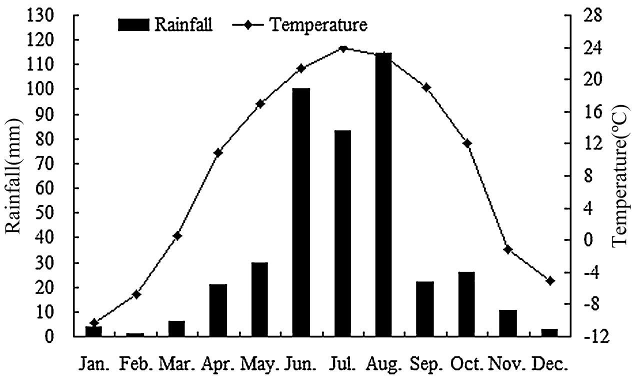

Fig. 1. Distribution of mean monthly rainfall and temperature at experiment site from 1999 to 2011.

2.2. Experimental design

The two factor experiment was designed as a randomized complete block with three replications in 9 m wide by 110 m long plots. The two soil management systems (treatments), conventional tillage with ploughing after straw removal (CTSR), and no tillage with subsoiling and straw cover (NTSC), were applied to the experimental plots in 1999 and maintained until 2011. The operation schedules for the CTSR and NTSC treatments are presented in Table 1. According to Wang et al. (2004) subsoiling depth should be in the range 20–30 cm, therefore annual subsoiling in the NTSC treatments was conducted to depth of 30 cm after harvest. In the CTSR treatment, tillage was conducted with a rotary cultivator (GQN-180) to an average depth 16 cm. A fallow period followed harvest until mid-April or early May, during which chemical weed control was applied as necessary. The spring maize (var. Danyu 86) was sown at rate of 30 kg/ha by a 2BG-5 no-till seeder. All in-crop fertilizer of NPK was applied at planting (N: 150 kg/ha, P: 140 kg/ha and K: 62 kg/ha).

2.3. Measured parameters

2.3.1. Weather

Rainfall and temperature were monitored throughout the experiment by a solar-powered automatic weather station, and data were recorded automatically by data loggers.

2.3.2. Bulk density

Soil bulk density was used as a significant indicator of changes in soil structure and water retention capacity (Arshad et al., 1999) and was progressively determined from 54 mm diameter cores to a depth of 30 cm (Blake, 1965). Five soil cores from each plot, cut into 5 cm increments (0–10 cm depth) and 10 cm increments (10–30 cm depth) were weighed on extraction and again after drying at 105 °C for 48 h in an oven to determine gravimetric soil water content and bulk density. Volumetric water content was determined from the product of gravimetric water content and soil bulk density values.

2.3.3. Pore size distribution

Soil pores were classified as macro-pores (consisting of pores with an equivalent radius >60 μm) and meso-pores (<60 μm). Macroporosity and mesoporosity were taken as the volumetric soil

Table 1
Operation schedule conducted annually for NTSC and CTSR treatments from 1999 to 2011.

Treatments	Operations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
CTSR	Fertilizing, ploughing, leveling and planting				■								
	Herbicide application					■							
	Mechanical harvesting, manual residues removal										■		
NTSC	Subsoiling										■		
	No tillage planting				■								
	Herbicide spraying				■								
	Mechanical harvesting, residues cover										■		

water content of the soil samples between 0 and −5 kPa and between −5 and −15 kPa matric potentials respectively.

2.3.4. Water-stable aggregation

The distribution of water-stable soil aggregates (WSA) was determined by placing soil samples on a nest of sieves, that were immersed in water, and agitated up and down by 35 mm at a rate of 30 cycles per minute for 15 min. The dried soil samples on each sieve determined the proportions of water-stable aggregates as those >2, 2–1, 1–0.25, and <0.25 mm. The WSA of <0.25 mm were classified as micro-aggregates after Oades and Waters (1991).

2.3.5. Soil salt content, and PH, organic matter and available P

Total soil salt content was determined by precipitation using an appropriate $AgNO_3$ Standard titration for each soil core, at each soil depth increment. The pH of a 1:5 soil water suspension of all the soil samples was determined by a portable pH meter. Air-dried soil samples taken from the field at the same depths and quantities as previously described, were used to determine soil organic matter (SOM) content by the dry combustion method, as described by Nelson and Sommers (1982). Soil total nitrogen (STN) was also determined from the air-dried soil samples using the Kjeldahl digestion method. An estimate of P fertility (available phosphorus) for each soil sample was measured using the bicarbonate extraction method (Olsen and Sommers, 1982).

2.3.6. Yield

Maize yields were determined by manual harvesting, threshing and air-drying grain to 13% moisture content from three 5 m lengths of three rows taken randomly from each of the replicated treatments.

2.3.7. Water use efficiency

Apparent evapotranspiration (AET) was calculated using a simplified water balance equation:

$$ET = (P + I) - \Delta S$$

where P was the in-crop rainfall and ΔS was the change in stored soil water of the 100 cm soil profile during the growing period. Irrigation was not applied during the growing period and runoff and deep drainage were assumed to be negligible, thus were not included in the water balance determination of ET.

Production water use efficiency (WUE) was calculated as the crop yield (kg/ha^{-1}) divided by the growing-season evapotranspiration (mm):

$$WUE = \frac{Yield}{ET}$$

2.4. Statistical analysis

Mean values were calculated for each of the measured variables, and ANOVA was used to assess the treatment effects. When ANOVA indicated a significant F-value, multiple comparisons of annual mean values were performed by the least significant difference method (l.s.d.). Statistical analyses were conducted with SPSS 13.0.

3. Results

3.1. Soil bulk density

There was no significant difference in soil bulk density between treatments at the commencement of the experiment in 1999 (Table 2). However, after 12 years, bulk density of NTSC treatment had decreased by 5.44%–11.98% in the 0–30 cm soil layer in

Table 2
Mean bulk density (g/cm^3) at 0–30 cm soil depths for NTSC and CTSR treatments in 1999 and 2011.

Year	Treatments	0–5 cm	5–10 cm	10–20 cm	20–30 cm
1999	CTSR	1.49^a	1.51^a	1.55^a	1.68^a
	NTSC	1.47^a	1.50^a	1.52^a	1.54^a
2011	CTSR	1.46^a	1.47^a	1.53^a	1.67^a
	NTSC	1.32^b	1.39^b	1.44^b	1.47^b

Values within a column in the same year followed by the same letters are not significantly different ($P < 0.05$).

comparison with the initial values. The improvement in soil bulk density was greater at depth, particularly in the 20–30 cm soil layer, where it reduced from 1.67 to 1.47 g/cm^3.

3.2. Soil porosity

Pore size class distribution for all soil depths significantly improved under NTSC treatments between 1999 and 2011 (Table 3). Total porosity in each of the four sampled layers in NTSC increased by 7.4 cm^3/100 cm^3 (35.4–42.8 cm^3/100 cm^3) compared with CTSR, which translated to an average improvement of 20.9%. These changes in soil porosity were consistent with the positive changes in bulk density. Although these changes were significant across all pores size class, the largest changes occurred in aeration porosity (macropores). In the 0–5 cm soil layer, aeration porosity was 101.5% significantly ($P < 0.05$) higher for NTSC than for CTSR with similar changes in magnitude found in the deeper soil layers. Capillary porosity improvement of 21.7%–35.5% appeared marginal, but nevertheless statistically significantly different under NTSC than under CTSR, for all layers. Micro-porosity remained the dominate pore size class in CTSR treatments (14.1–17.3 cm^3/100 cm^3) and was significantly high than that of NTSC treatments (9.8–14.7 cm^3/100 cm^3) at all depths. Whereas capillarity porosity tended to be the dominate pore size class under NTSC the results reflected a slightly less skewed dominance of one class over another.

3.3. Water-stable aggregates

The effects of different tillage methods on the water stability of soil aggregates are shown in Table 4. In all four layers (0–5, 5–10, 10–20 and 20–30 cm), water-stable aggregates of the largest size class (>2 mm) were 63.1%-80.3% ($P < 0.05$) greater under NTSC than under CTSR. Similarly the percentage of water stable macro-aggregates (>0.25 mm) to a depth of 20 cm in NTSC was significantly greater than that of the CTSR treatments. In contrast, the percentage of water-stable aggregates of the smallest size class (<0.25 mm) in the three upper layers (0–5, 5–10 and 10–20 cm) was 9.8%-23.2% significantly lower ($P < 0.05$) in NTSC plots compared with in CTSR treatments.

Table 3
Soil pore size distribution for NTSC and CTSR treatments at the 0–5, 5–10, 10–20 and 20–30 cm soil depths in 2011.

Soil depth (cm)	Treatment	Soil pore size distribution, cm^3/100 cm^3			
		Total porosity	Aeration porosity (>60 um)	Capillary porosity (0.2–60 um)	Microporosity (<0.2 um)
0–5	CTSR	36.7^{a}	6.5^{a}	16.1^{a}	14.1^{a}
	NTSC	45.1^{b}	13.1^{b}	19.6^{b}	12.4^{b}
5–10	CTSR	36.8^{a}	3.2^{a}	16.3^{a}	17.3^{a}
	NTSC	44.2^{b}	9.2^{b}	20.3^{b}	14.7^{b}
10–20	CTSR	34.2^{a}	3.0^{a}	17.1^{a}	14.1^{a}
	NTSC	40.1^{b}	8.6^{b}	21.7^{b}	9.8^{b}
20–30	CTSR	33.7^{a}	2.8^{a}	16.3^{a}	14.6^{a}
	NTSC	41.6^{b}	8.3^{b}	22.1^{b}	11.2^{b}

Values within a column in the same soil depth followed by the same letters are not significantly different ($P < 0.05$).

Table 4
Soil wet stable aggregate size classes (mm) for NTSC and CTSR treatments at 0–5, 5–10, 10–20 and 20–30 cm depths (%) in 2011.

Soil depth (cm)	Treatment	Aggregate size classes				
					Macro-aggregates	Micro-aggregates
		>2	2–1	1–0.25	>0.25	<0.25
0–5	CTSR	2.6^{a}	4.0^{a}	48.6^{a}	55.2^{a}	44.8^{a}
	NTSC	8.1^{b}	3.8^{a}	44.3^{a}	56.2^{b}	43.8^{a}
5–10	CTSR	1.6^{a}	5.5^{a}	48.2^{a}	55.3^{a}	44.7^{a}
	NTSC	4.4^{b}	8.8^{b}	47.6^{a}	60.8^{b}	39.2^{b}
10–20	CTSR	1.2^{a}	6.5^{a}	39.1^{a}	46.8^{a}	53.2^{a}
	NTSC	6.3^{b}	5.8^{a}	45.0 ^{b}	57.1^{b}	42.9^{b}
20–30	CTSR	1.3^{a}	13.8^{a}	53.6^{a}	68.7^{a}	31.3^{a}
	NTSC	6.0^{b}	5.6^{b}	46.3^{b}	57.9^{a}	42.1^{a}

Values within a column in the same soil depth followed by the same letters are not significantly different ($P < 0.05$).

Table 5
Soil salt content at 0–30 cm soil depths for NTSC and CTSR treatments in 2011.

Depth (cm)	Treatment	pH	Ca^{2+} (%)	Mg^{2+} (%)	$K^{+} + Na^{+}$ (%)	Salt content (%)	Water content (%)
0–5	CTSR	8.95^{a}	0.28^{a}	0.14^{a}	0.27^{a}	2.68^{a}	13.2^{a}
	NTSC	8.09^{b}	0.23^{b}	0.06^{b}	0.05^{b}	1.67^{b}	15.7^{b}
5–10	CTSR	8.68^{a}	0.27^{a}	0.16^{a}	0.27^{a}	2.54^{a}	15.2^{a}
	NTSC	8.16^{b}	0.22^{b}	0.02^{b}	0.06^{b}	1.17^{b}	18.2^{b}
10–20	CTSR	8.97^{a}	0.29^{a}	0.13^{a}	0.42^{a}	2.54^{a}	16.1^{a}
	NTSC	8.26^{b}	0.23^{b}	0.07^{b}	0.11^{b}	1.26^{b}	19.9^{b}
20–30	CTSR	8.97^{a}	0.38^{a}	0.21^{a}	0.67^{a}	3.61^{a}	18.3^{a}
	NTSC	8.36^{b}	0.30^{b}	0.08^{b}	0.21^{b}	2.12^{b}	21.4^{b}

Values within a column in the same soil depth followed by the same letters are not significantly different ($P < 0.05$).

3.4. Soil chemical properties

3.4.1. Soil salt content and PH

The total salt content in the soil profile to a depth of 30 cm was almost halved (45.3%) under NTSC treatments, decreasing significantly from 2.84 to 1.55% after 12 years (Table 5). Notably the least change (difference between treatments) in total salt was in the 20–30 cm soil layer. Accordingly, mono and divalent cation concentration was significantly less by 73.4%, 64.3%, and 20.3% for $K^+ + Na^+$, Mg^{2+} and Ca^{2+} respectively, for CTSR in comparison to the NTSC treatments. After 12 years the pH of NTSC treatment decreased by a small, but statistically significant margin (6.3%–10.6%) in the 0–30 cm soil layer in comparison with that of CTSR treatments.

3.4.2. Soil organic matter

NTSC treatments resulted in significantly higher ($P < 0.05$) levels of SOM in the measured soil profile (0–30 cm) as shown in Table 6. Average SOM in the 0–5 and 5–10 cm layers of NTSC treatments was 45.7% and 34.7% higher respectively than that in CTSR treatments. A similar pattern was found in the 10–20 and 20–30 cm layers, where the average SOM in NTSC was 25.3% and 21.1% higher respectively than CTSR.

3.4.3. Soil total nitrogen

In the 0–5 and 5–10 cm soil depths, STN under NTSC was 76.2% and 70% lower in comparison with CTSR, while STN values were not significantly different below 10 cm (Table 6). Taking 1999 as the initial point of reference, STN (0–30 cm) increased by 3.6% on NTSC treatments, whereas CTSR treatments increased 12.5% by accumulating STN in the surface layers.

3.4.4. Available P

Available P was significantly ($P < 0.05$) different by 28.13% and 32.9% for NTSC in the 0–5 and 5–10 cm soil layers respectively, in comparison with CTSR (Table 6). However these changes were not reflected in deeper soil layers.

3.5. Spring maize yield

Treatments effects on maize yield were not significantly different in the first 3 years. While over the following three years (2003–2006) average yield remained relatively unchanged for CTSR treatments, the average maize yields for the NTSC continued to increase until 2006, when it tended to plateau at ~9 t/ha, but remain significantly different to that of the variable and lower yielding crops of the CTSR treatments (Fig. 2). Average spring maize yields from 2004 to 2011 under NTSC were 15.1%–36.9% higher than under CTSR treatments, while they were only 2.52%–9.71% higher from 1999 to 2003.

Table 6
Soil chemical properties for NTSC and CTSR treatments in 2011.

Soil depth (cm)	Treatment	SOM (g/kg)	STN (mg/kg)	Available P (mg/kg)
0–5	CTSR	17.5^a	1.21^a	9.03^a
	NTSC	25.5^b	0.98^b	11.57^b
5–10	CTSR	17.3^a	1.08^a	8.5^a
	NTSC	23.3^b	0.87^b	11.3^b
10–20	CTSR	16.2^a	0.82^a	6.8^a
	NTSC	20.3^b	0.86^a	8.17^a
20–30	CTSR	15.2^a	0.73^a	4.97^a
	NTSC	18.4^b	0.68^a	5.1^a

Values within a column in the same soil depth followed by the same letters are not significantly different ($P < 0.05$)

Table 7
Water use efficiency for NTSC and CTSR treatments in different years.

Treatments	1999	2003	2007	2011
NTSC				
Rainfall (mm)	489	640	621	675
ΔS (mm)	30.8	39.8	48.6	59.8
WUE ($kg\,ha^{-1}\,mm^{-1}$)	6.19^a	12.08^a	15.80^a	15.05^a
CTSR				
Rainfall (mm)	489	640	621	675
ΔS (mm)	33.2	38.2	43.7	48.9
WUE ($kg\,ha^{-1}\,mm^{-1}$)	5.91^a	11.12^a	12.71^b	11.71^b

Values within a column in the same soil depth followed by the same letters are not significantly different ($P < 0.05$).

3.6. Water use efficiency

WUE was 24.3% and 28.5% significantly higher under NTSC than CTSR treatments, respectively in the latter years of the experiment (Table 7). As yields were not significantly different in the early years, so too WUE from 1999 to 2003, was not different between treatments.

4. Discussion

The experiment conducted from 1999 to 2011 demonstrated that no-tillage with subsoiling and straw cover had a significant impact on total soil salt, soil physical and chemical properties and yield. The resultant lower bulk density under NTSC after 12 years

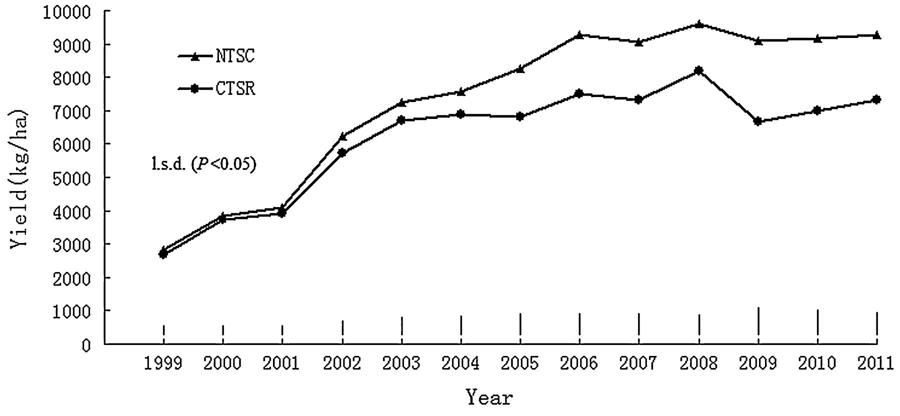

Fig. 2. Spring maize yield (kg/ha) for CTSR and NTSC treatments during experiment period.

was slight and generally attributed to a combination of continuing subsoiling followed by no-tillage. However soil porosity, pore size class distribution and water stable aggregates also underwent important and significant improvements. These significant structural changes could be attributed to the no-tillage, higher soil organic matter content, increased biological activity, as well as improved drainage and aeration, which could be indicative of improved soil health in the NTSC treated sites (Karlen et al., 1994; Schjonning et al., 1994; He et al., 2007).

Tillage generally alters soil porosity (Roseberg and McCoy, 1992) but its effects are quite transitory, which was reflected in the worsening soil physical condition of the conventional tillage treatment, for example, predominance of microporosity. The consistent improvement in overall soil porosity under NTSC was most probably related to increased aggregate stability, enhanced by minimum tillage, residue cover and biological activity. This treatment also had a better distribution of the various pore size classes which is very important for the crop growth, since it influences plant available water, soil aeration, through increased connectivity, drainage and channeling for enhanced root development (Oliveira and Merwin, 2001). The significant improvement in macropore volume in NTSC was consistent with the findings of Xu and Mermoud (2001), who demonstrated that subsoiling in the North China Plain significantly increases the volume of larger pores (>50 μm diameter) in the 0–40 cm soil layer, when compared to conventional intensive ploughing.

The changes in total salt concentration might well be enhanced by subsoiling, but is more likely due to protection of the soil surface from hardsetting, improved pore size class distribution, aggregate stability and the resultant improvement in infiltration capacity and hydraulic conductivity to leach salt below the root zone (Ji et al., 2007). Furthermore, the straw cover in NTSC treatments protected the soil from water evaporation, thus preventing salt from accumulating in the surface soil layers (Chi et al., 1994; Li et al., 1999; Zhang and Zhang, 2009). The quantity of salt leaching from the top layer due to the straw cover and subsoiling was particularly relevant, especially for the highly mobile and undesirable Na^+ cation. The desirable CA^{2+} cation remained in the profile for flocculation and aggregation of the soil particles. Whereas the continued presence of Na^+ ions in the CTSR profile would have tended to disperse the soil particles, cause surface crusting and limit rainfall infiltration, thus perpetuate the soil degradation issues of conventional farming practices.

Soil aggregates are an important component of soil fertility and productivity and play a key role in water infiltration (Zhang et al., 2006). Moreover, the properties of soil aggregates have a major influence on root development, water availability and C and nutrient cycles, and soil resistance to erosion and degradation (Kay, 1998). The change in the % of water-stable aggregates was consistent with general aggregation from the leaching of sodium, increases in porosity and adoption of minimum tillage. The increase in soil aggregates in those soils, where minimum tillage was adopted, was demonstrated by Tisdall and Oades (1982). The aggregate stability on the soil surface (related to reduced sodium above and rainfall impact) as a result of residue cover and no-tillage can also be seen as important factors contributing to soil quality (Oyedele et al., 1999). Additionally, previous studies found that by shifting from conventional tillage to no tillage can decrease soil losses through erosion by up to 79% (Zhang et al., 2004; Wang et al., 2006) through soil surface protection increased infiltration and reduced runoff.

The significantly higher SOM in the NTSC treatment especially in the surface layers, was attributed to increased input from crop residues and considerable reduction in soil disturbance. The intensive tillage and residue removal of the CTSR treatments continued to contribute to significant SOM losses. Similarly, Zibilske et al. (2002) also reported that no-tillage concentrated soil organic matter and carbon in the top soil layer in a semi-arid alkaline subtropical soil, where in a comparison with conventional tillage, no-tillage significantly increased soil organic matter by 57.8% and 15.1% in the 0–4 and 4–8 cm soil layers respectively, after 10 years of no tillage management. Roldan et al. (2005) reported that no tillage with subsoiling treatments in Mexico increased SOC by up to 15% in the 0–5 cm layer and furthermore, no tillage reduced carbon oxidization and losses to the atmosphere.

STN under NTSC was lower than that under CTSR treatments, which may be attributed to Nitrogen "tieup", from the amount of maize straw cover and enhanced biological activity, but also Nitrogen is highly mobile in the soil solution and may have been leached with the increased drainage capacity of the NTSC treatments. However, Zhu and Yue (2004) and Wang et al. (2007) reported that retaining maize residue on the soil surface enhanced microbial activity and consumption of Nitrogen. Although increasing amounts of residue on the soil surface had a positive effect on maize growth, higher amounts of N were required in the initial years of conservation tillage to compensate for short term reductions in plant available N.

No-tillage with straw cover had significantly ($P < 0.05$) higher concentrations of available P in the upper soil layers (0–5, 5–10 and 10–20 cm), while lower layers (20–30 cm) were not affected, which was consistent with Zhang et al. (2010). The topsoil accumulation of P in NTSC can be explained by the downward movement of P-bound particles in no-till soil and the upward movement of nutrients from deeper layers through nutrient uptake of plant roots (Urioste et al., 2006).

The improvement of yield under NTSC may be due to the improvement in available soil water, combined with a general increase in fertility and soil health. More importantly, soil salinity was in the range of medium to high in the CTSR treatments, therefore the maize would have been under considerable salinity and water stress for most of the growing period. Soil salinity greater than 1.3% TSS or an ECse >3.8 dS/m will reduce potential yield of maize by at least 25%, so even under NTSC treatments the crop could have been limited by some salinity stress at 1.55% total salt content. Therefore there is scope for further interventions to reduce salinity and improve yields. However the high pH of this soil remains a concern, this is because at these high pH levels Ca^{2+} and Mg^{2+} ions can become insoluble, increasing further soil degradation from Sodium. With further leaching, pH may decrease with time, but other more timely solutions could include the application elemental sulphur, incorporating composts (organic acids) or extensive use of cover crops where possible.

Therefore the somewhat simple act of retaining crop residues on the soil surface and limiting tillage to annual subsoiling, has a significant impact on soil physical structure, rainfall utilization, salinity reduction, soil amelioration and sustainable cropping. NTSC is of particular interest for those areas of Northeast China affected by salinity and soil degradation issues and is very suitable for soil amelioration, improving soil health and increasing crop yields.

5. Conclusions

The study conducted from 1999 to 2011 clearly demonstrated that no-tillage with subsoiling and straw cover is associated with a substantial improvement in soil properties, nutrient status and yields in those areas of Northeast China affected by soil salinization as compared to conventional tillage with ploughing and straw removal. Data indicated that the adoption of NTSC significantly improved a wide range of soil physical attributes and thus reduced root zone salinity by almost 50%. In contrast, frequent top soil (0–

15 cm) tillage and residue removal in CTSR treatment resulted in impeded infiltration, so that the salinized soils could not be ameliorated.

The resultant positive changes in soil structure, improved soil health, nutrient availability, reduced salinity and reduced water stress under NTSC soil management contributed to significantly higher spring maize yields and therefore is a significant step forward for sustainable cropping in NE China.

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