JARQ 50 (3), 191 - 199 (2016) http://www.jircas.affrc.go.jp

An Evaluation of Minimum Tillage in the Corn-wheat Cropping System in Hebei Province, China: Wheat productivity and water conservation

Xiaomei YANG[1], Changbin YIN[1], Hsiaoping CHIEN[3], Guichun LI[2] and Fujio NAGUMO[3]*

[1] Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences (Beijing, 100081, China)
[2] Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences, (Beijing, 100081, China)
[3] Japan International Research Center for Agricultural Sciences (Tsukuba, Ibaraki 305-8686, Japan)

Abstract

In North China where the main crops are winter wheat and summer corn, current agricultural practices involve minimum tillage for corn and full tillage for corn or wheat, and require large amounts of irrigation water, especially during the wheat growing season. Conservation tillage (CT) is a promising method of water conservation, but local farmers still question whether it will affect the yield of winter wheat. We conducted fieldwork during 2011-2014 in Xushui, Hebei, China, in order to compare the effects of various methods of tillage, mulching, and irrigation on the yield, soil moisture, and soil temperature under a summer corn/winter wheat double cropping system. Wheat grain yield in 2012-2013 did not differ significantly because of tillage, residue, and irrigation treatments. This means that reduced irrigation did not affect grain yield for all the treatments. However, in 2013-2014, the yield for minimum tillage with residue mulch (MT_m) was significantly higher (19.5%) than that for full tillage with residue removal (FT_r). Yields for MT_m with reduced irrigation were 10.2% significantly higher than FTi with reduced irrigation. The positive crop response to MT_m may have been due to relatively higher topsoil moisture and soil temperature under MT_m than under FT_i during the winter period. Minimum soil temperature for the inter-row at the 5-cm depth under MT_m remained slightly higher than that under FT_i during the winter of 2012–2013, with colder weather than in 2013-2014. Hence, after our two-year field experiment, we concluded that MT_m resulted in higher grain yields as compared with FT_r probably due to higher topsoil water content; MT_m with reduced irrigation maintained high yields despite eliminating one round of irrigation. Therefore, MT_m with reduced irrigation was more beneficial for winter wheat crop production in North China.

Discipline: Crop production
Additional key words: crop residue, soil temperature, soil water content, yield

Introduction

North China possesses approximately 3.6 × 10^7 ha of arable land, accounting for about 30% of China's total arable land, and produces up to 42% and 79% of China's corn and wheat, respectively (Du 2013). In this area, grain yield largely depends on irrigation; consequently, agricultural irrigation consumes more freshwater than that for other uses. North China is currently confronted with ever-greater demands for water and widespread water shortages. The excessive use of groundwater for large-scale agricultural irrigation to produce high grain yields, and the decreasing water table in North China are issues of growing concern, not only among local residents but also government agencies and researchers (Zhang et al. 1999, Zhang et al. 2003, Qin et al. 2006, Pan et al. 2011). It is important to develop a new system of crop rotation designed to conserve water, while maintaining stable grain production.

Conservation tillage (CT) is well known and acknowledged as a promising tillage practice that focuses on reducing soil erosion and enhancing soil water conservation (Mannering &Fenster, 1983). CT generally involves no-

This paper reports the results obtained in the joint project (JIRCAS & CAAS) on "Recycling-based agricultural production system in upland farming areas of Northern China"
*Corresponding author: e-mail fnagumo@affrc.go.jp
Received 28 May 2015; accepted 20 November 2015.

tillage (NT), minimum tillage (MT), or at least reduced tillage, as well as crop residue mulching (Kong et al. 2009, Uri, 1997, Van den Putte et al. 2010). MT for corn has been the accepted and prevalent water conservation practice for some areas in North China. Kaspar et al. (1990) reported that CT retards crop growth and Unger (1978) reported that CT inhibits the early growth of crops. CT may negatively affect winter wheat growth in China's double cropping system. However, information regarding CT is contradictory. Xie et al. (2007) reported that the practice of CT results in lower wheat yield due to the relatively low tiller number and soil temperature as compared with FT. These characteristics of CT prevent its full implementation with wheat plantings in China. However, other researchers have demonstrated the positive effects of CT on crop yield due to improved soil conditions (Li et al. 2007, Su et al. 2007, He et al. 2011).

Therefore, the purpose of this experiment was to demonstrate the effects of MT and FT on winter wheat yield and tiller number, and evaluate the effects of MT on water conservation in North China. We hypothesized that the practice of reducing agricultural irrigation under MT_m will help conserve limited ground water, while maintaining adequate yield. We conducted our research in a double cropping system by monitoring soil water content and soil temperature throughout each crop's life cycle. Few studies have been conducted on this important topic.

Materials and methods

1. Site description

The experiment was conducted during 2011-2014 in Xushui County, Hebei Province, China (37.8°N, 114.7°E). The elevation ranged from 8 to 447 m above sea level, mean annual rainfall was approximately 500 mm, and mean annual temperature was 12°C over the past two decades (1993-2012, Fig. 1). The main crop rotation system is for winter wheat and summer corn, with growth periods from early October to mid-June, and from mid-June to the end of September, respectively. Precipitation during the wheat and corn growth seasons during our study years (2012-2013) totaled 163.5 mm and 430 mm, respectively, and during 2013-2014 totaled 74.0 mm and 253 mm, respectively. However, the average temperature (-5.3°C) in December 2012 in Hebei Province was 2-3°C lower than average and reached record low temperatures (Sun et al. 2014). The soil at the experiment site is classified as Haplic Luvisol (FAO classification), with a silty clay loam texture (clay 20.3%, silt 55.7%, sand 24.0%). Known locally as cinnamon soil, this soil is among the prominent types in North China. It had a pH of 7.5, soil organic carbon of 11.5 g/kg^{-1}, and soil total nitrogen of 1.1 g/kg^{-1} in 2011. Inorganic soil N (NH_4^+-N: 5.9 mg/kg^{-1}, NO_3^- -N: 14.3 mg/kg^{-1}), available

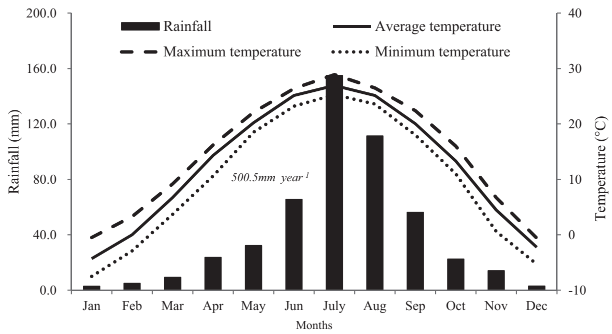

Fig. 1. Mean monthly rainfall and temperature at the experiment site (1993-2012)

soil P (17.1 mg/kg^{-1} as measured using the Olsen method), and available soil K (134.3 mg/kg^{-1} as determined by frame photometry after extraction with NH_4OAc solution) in the upper 20-cm layer of soil.

2. Experimental design and methods

A randomized complete block design with three replications was used for the tillage treatments. The 4 m × 5 m plots were separated by vertical barriers composed of waterproof plastic sheets buried to a depth of 1 m at the beginning of the experiment in 2011. The experiment involved various methods of tillage, mulching, and irrigation (Table 1). Soil under full tillage (FT) treatment was tilled to a depth of approximately 20 cm by a rotary cultivator machine to ensure full incorporation of the preceding corn residue (FT_i); this practice was followed by dragging a board attached to the machine across the ground to level the surface. The MT treatment was designed to minimize soil disturbance using a tilling depth of only 10 cm and a width of 20 cm for seed and fertilizer in-row placement alternatively with no inter-row 20-cm wide tilled area by using a small rotary tiller (Fig. 2). First, fertilizer was placed in a row in the middle of the tilled area, and then stripe sowing was conducted in two lines on both sides of the fertilizer line. The chopped corn residue with a size of 3-4 cm was spread evenly on the soil surface after sowing in the MT_m treatment. Farmers in this area typically apply irrigation water just after wheat sowing, before winter, and at the returning green and heading stages each spring. In this study, reduced irrigation was conducted without irrigation at the heading stage for both MT_m and FT_i treatments. Based on the farmers' traditional irrigation practices, the conventional irrigation frequency in 2012-2013 was four times (200 mm in water volume) and three times (150 mm) in 2013-2014, respectively. The reduced irrigation frequency was three times (150 mm) in 2012-2013 and two times (125 mm) in 2013-2014. Thus, the reduced irrigation treatment conserved 25-29% of the irrigation water.

The seeds of a local variety ('Bao Mai No. 9') were

Table 1. Experimental design of treatment groups with differing tillage, residue, and irrigation

	Residue treatment	Irrigation treatment
FT	Incorporation (FT_i)	Conventional
		Reduced
	Removal (F_{Tr})	Conventional
MT	Mulch (MT_m)	Conventional
		Reduced
	Removal (MT_r)	Conventional

Conventional irrigation is the application of irrigation four times during the wheat growth season in 2012-2013 and three times in 2013-2014 according traditional farming practices. Reduced irrigation eliminated one round of irrigation as compared with conventional irrigation.

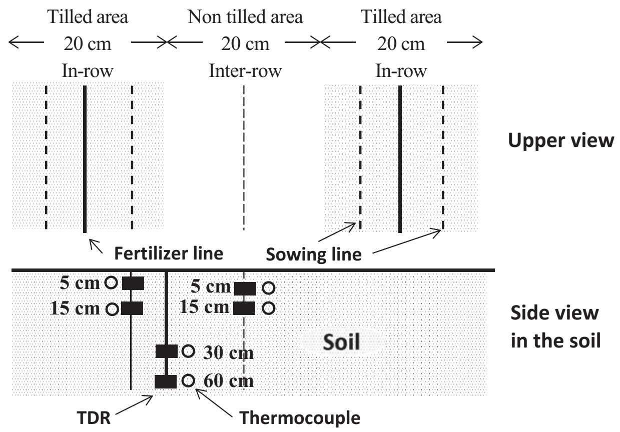

Fig. 2 Pattern of tilled and non-tilled areas of wheat cultivation and locations of time-domain reflectometer sensors and thermocouples

sown at a seeding rate of 275 kg/ha^{-1} in 2011-2012 and 300 kg/ha^{-1} in both 2012-2013 and 2013-2014. As basal application, composite fertilizer was applied at a rate of 130 kg N, 159 kg P_2O_5, and 43 K_2O kg/ha^{-1} for all the plots. As topdressing, urea was applied at a rate of 70 kg N/ha^{-1} at the returning green stage: April 22nd (197 days after planting (DAP)) for 2012-2013, April 12th (188 DAP) for 2013-2014, respectively.

3. Monitoring of soil water content and temperature

Time-domain reflectometers (TDR, CS 616, Campbell Scientific, Logan, UT, USA) were installed horizontally in the in-row and inter-row areas at depths of 5 and 15 cm, respectively, and along the border between both areas at depths of 30 and 60 cm, respectively (Fig. 2). In the case of FT treatment, although all soil surfaces were tilled, the locations of the TDRs were the same as for MT. Volumetric soil water content was recorded at 20 min. intervals. Stored soil water content in the profile was calculated at each soil layer (at depths of 0-10, 10-20 and 20-40 cm), assuming that the volumetric water content at depths of 5, 15 and 30 cm represents each soil layer, respectively. Said water content was calculated for soil layers of 0-10 and 10-20 cm after averaging the in-row and inter-row values. Soil temperature thermocouples made from copper constantan wire were installed horizontally at depths of 5, 15, 30 and 60 cm adjacent to the sensors of the TDRs.

4. Crop growth and yield

Because the past condition of fields greatly influenced winter wheat production during 2011-2012, the wheat yields during 2012-2013 and 2013-2014 are discussed in this paper. Four 0.5-m-long rows per plot were selected for measuring the total tiller number (collected four times): during the seedling emergence stage (October 25, 2013), the winter period (December 06, 2013), the returning green stage (April 8, 2014), and at the harvest-ready stage (June 11, 2014). Similarly, six 1-m samples were hand-harvested and weighed on the date of maturity; two of these samples with outlying data were excluded from the analysis. The wheat grain was first air-dried after being separated from the stems. The dry grain weight was determined after drying in an oven at 80°C for 24 hours. Then the grain yield and its components were calculated. To compare the effects of tillage treatments, an analysis of variance (ANOVA) was conducted using the SPSS analytical software package (IBM Corp, USA). The testing of significant differences was determined by Turkey's HSD ($P < 0.05$).

Results and discussion

1. Changes in water content during the cropping period

Figure 3 shows the changes in soil water content during the cropping period in 2013-2014. Soil water content at MT_m was much higher than at FT_i in the inter-row at the 5-cm depth (Fig. 3 (A)). However, there was no clear difference in water content between FT_i and MT_m at the in-row 5-cm depth (Fig. 3 (B)). As shown in Fig. 3 (A), the soil water content at FT_i during the initial stage ranged

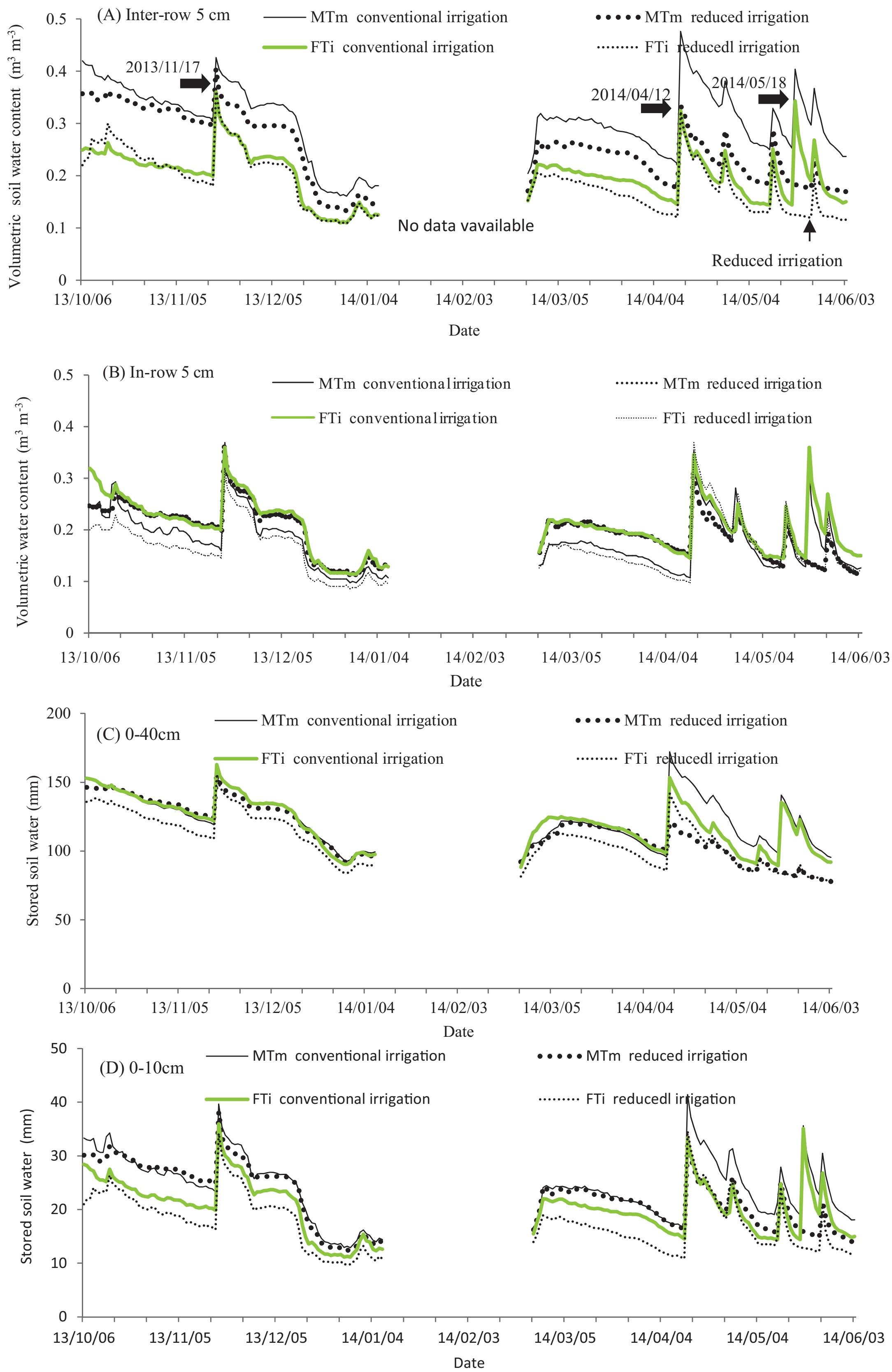

Fig. 3. Changes in soil water content and stored soil water for the four tillage systems during the cropping period
Volumetric soil water content at (A) inter-row sites at 5-cm depth, (B) in-row sites at 5-cm depth, stored soil water at (C) 0-40 cm, and stored soil water at (D) 0-10 cm (The dates in Fig. 3 (A) indicate those of irrigation with VWC peak.)).

between 0.2 and 0.3 m^3 m^{-3} while that in non-tilled soil (inter-row at MT_m in Fig. 3 (A)) ranged between 0.3 and 0.4 m^3. The increased macro-pores due to tillage may have resulted in lower soil water content. In addition, the soil at MT_m was mulched by corn residue, which maintained a higher soil water content (Fig. 4). There was a relatively higher discrepancy in soil water content at the in-row 5-cm depth for both FT_i and MT_m. This was probably due to more variable microenvironments around the TDR sensors because of tillage. No major differences among the treatments were observed at 15, 30 and 60-cm depths (data not shown).

There was no significant difference among the treatments in stored soil water of the 0-40 cm soil layer during the cropping period (Fig. 3 (C)) while that at the surface layer (0-10 cm) of MT_m was much higher than that of FT_i (Fig. 3 (D)). This was mainly due to higher soil water content at the inter-row (non-tilled soil). Soil water content in shallow soil is believed to be a critical factor for the successful production of crops during the initial and flowering stages (Alvarez & Steinbach, 2009); likewise, in this study, MT_m treatment resulted in improved grain yield as shown in Table 2.

2. Changes in soil temperature during the cropping period

Interestingly, the minimum soil temperature for the inter-row at the 5-cm depth under MT_m conventional irrigation remained slightly higher than that of FT_i conventional irrigation treatments during winter from late November to early January in 2012-2013 (Fig. 5 (A)). However, during winter from late November to early January in 2013-2014, the minimum soil temperature between MT_m conventional irrigation and FT_i conventional irrigation treatments decreased in line with the same trend (Fig. 5 (B)). This may indicate that higher soil temperature in MT_m during winter in 2012-2013 (about 2°C lower than in 2013-2014) provided a relatively warm environment for seedlings to survive the winter. This likely occurred because residue cover in the MT_m treatment insulated the soil. Residues normally

Fig. 4. Surface features in minimum tillage with mulch residue and full tillage with residue incorporated (April 3, 2013)

Table 2. Grain yield of wheat in a wheat-corn double cropping systems under MT_m and FT_i with different types of irrigation management (2012-2013 and 2013-2014)

Year	Treatment	Panicle number (× 1000)ha^{-1}	Grain number /panicle	Thousand grain weight (g)	Panicle weight (g)	Yield kg ha^{-1}
2012-2013	MT_m reduced irrigation	7402 ± 273	22.6 ± 1.6	35.2 ± 0.8a	0.80 ± 0.05	5886 ± 181
	MT_m conventional irrigation	7152 ± 504	24.4 ± 0.7	33.2 ± 1.2ab	0.81 ± 0.02	5784 ± 366
	FT_i reduced irrigation	7144 ± 35	24.9 ± 0.9	31.6 ± 0.7b	0.79 ± 0.04	5605 ± 53
	FT_i conventional irrigation	6631 ± 573	25.6 ± 2.6	32.7 ± 0.8b	0.84 ± 0.10	5520 ± 176
2013-2014	MT_m reduced irrigation	6569 ± 518	26.4 ± 2.9	40.3 ± 1.9	1.06 ± 0.10	6931 ± 165b
	MT_m conventional irrigation	6839 ± 758	28.3 ± 1.6	39.5 ± 2.4	1.12 ± 0.11	7608 ± 347a
	FT_i reduced irrigation	6119 ± 266	25.5 ± 1.1	40.3 ± 2.6	1.03 ± 0.04	6289 ± 162c
	FT_i conventional irrigation	6133 ± 570	29.1 ± 3.0	42.0 ± 0.9	1.22 ± 0.11	7460 ± 149ab

Values with different letters are significantly different among the treatments each year ($P < 0.05$); values without letters are not significantly different ($P < 0.05$).

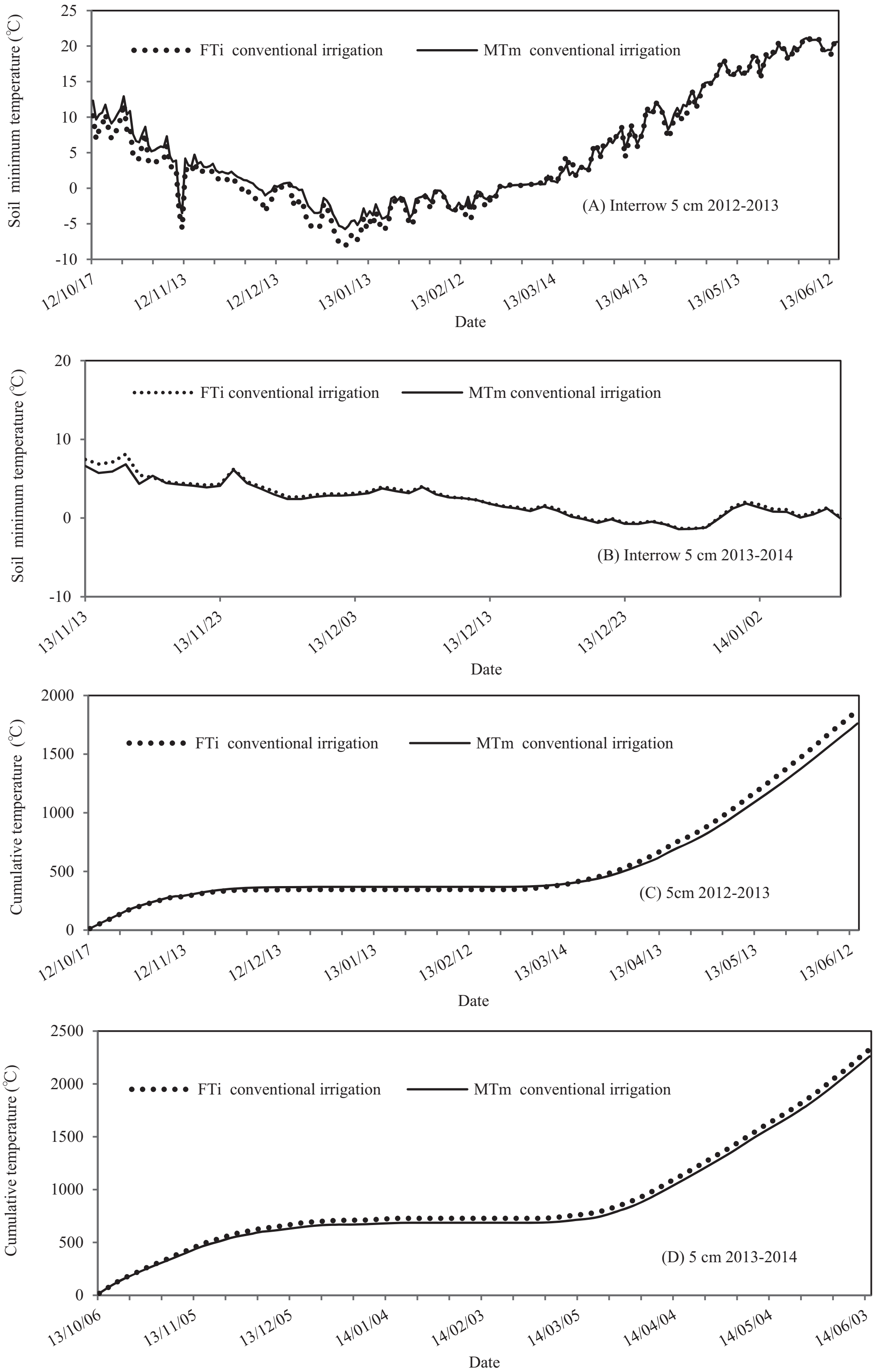

Fig. 5. Changes in soil temperature under different tillage systems

(A) Inter-row temperature at a depth of 5 cm in 2012-2013, (B) Inter-row temperature at a depth of 5 cm from late November to early January in 2013-2014, (C) Cumulative soil temperature at a depth of 5 cm (average of inter-row and in-row) in 2012-2013, and (D) Cumulative soil temperature at a depth of 5 cm in 2013-2014.

form a protective cover between the air and soil, reflecting solar radiation and preventing heat loss (Shinners et al. 1994). We observed a similar trend for the in-row 5-cm depths, but the minimum soil temperature at other soil depths showed no major differences between MT_m and FT_i conventional irrigation systems (no data shown).

A comparison of cumulative soil temperature at 5 cm (average of inter-row and in-row) between 2012-2013 and 2013-2014 reflected lower air temperature in 2012-2013 than in 2013-2014 as described above (Fig. 5 (C) and (D)). There was little difference under FT_i and MT_m with conventional irrigation during the winter wheat growth period. This suggests that minimum tillage with mulch residue should not be considered a negative factor for winter wheat growth. At harvesting time, however, cumulative soil temperature at FT_i was higher (6.6% and 3.0%) than at MT_m in 2012-2013 and 2013-2014, respectively.

3. Tiller number during the cropping period

Figure 6 shows the tiller number under the tillage/residue treatments in 2013-2014 that included the emergence of seedlings, wintering period, and returning green stage, as well as the harvest-ready stage. The tiller number for MT_r treatment was similar to the other tillage tiller numbers. Li et al. (2008) found that the number of wheat tillers produced with NT was significantly lower than that of conventional tillage. However, they believed that the lower emergence rate of NT was mainly due to the low performance of non-till planters in Luan Cheng, Hebei Province, China, and that the lower temperature in NT soil than in conventional tillage during the seedling period and returning green period may be less important. Negative effects of CT were also reported from Luan Cheng, where the practice of NT and MT resulted in low soil temperature during the returning green stage of winter wheat growth and thus negatively affected the emergence rate and wheat yields (Dong et al.2007). However, in our study, MT_m did not reduce the tiller number. Similarly, in Henan Province, where NT with mulch residue effectively increased the tiller number, along with sufficient soil moisture and topsoil nutrient content (Huang et al. 2009). Under CT, the emergence of winter wheat in Xiang He County, Hebei Province was delayed for only one or two days, which had no effect on crop growth (Zhou et al. 2001). Moreover, CT with residue retention conserved soil heat, allowing soil warming at times with low soil temperatures and the moderation of soil temperatures when the temperature was high; this allowed a relatively constant temperature to be maintained in Inner Mongolia for *Avena sativa* growth, but had no effect on the seedling emergence rate (Liu et al. 2014). Furthermore, greater winter wheat seedling emergence rates in winter wheat-fallow systems in eastern Colorado, USA depend on greater soil water under NT, and lead to higher grain yields

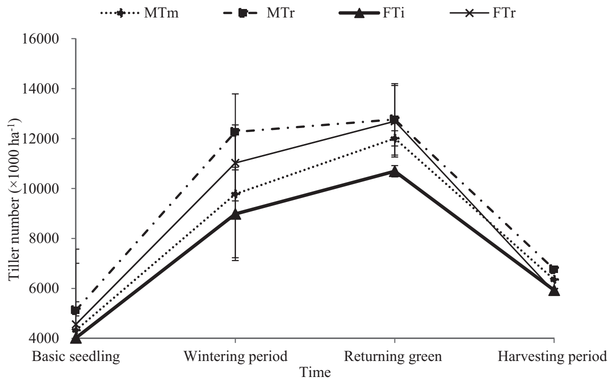

Fig. 6. Tiller number per hectare during the cropping period of 2013-2014
(Error bars show the standard deviation.)

(McMaster et al. 2002).

4. Effects of tillage and irrigation management on grain yield

Table 2 shows the yield and yield components for two consecutive years. Wheat yield using the MT_m reduced irrigation treatment during 2012-2013 was not statistically different among the four treatments, with a modest 25% reduction of irrigation water applied during the heading stage of plant growth. While wheat yield using the MT_m reduced irrigation treatment during 2013-2014 was statistically significantly higher than that using the FT_i reduced irrigation treatment (by 10.2%), it was not significantly different from FT_i conventional irrigation treatment, with a 29% reduction of irrigation water. This showed that irrigation could be reduced by one irrigation practice under MT with mulch residue management, which agrees with the results of research conducted in Beijing, China (Peng 2010). In addition, Cui et al. (2014) reported that applying 25% less irrigation water would improve crop yield for winter wheat.

A comparison of yield and yield components between 2012-2014 and 2013-2014 showed some differences. The averaged thousand grain weight and grain yields in 2013-2014 were significantly higher than in 2012-2013. This could be attributed to the best climatic conditions during the past five years for winter wheat growth during the 2013-2014 season, along with substantial rainfall from October 9 to November 24, 2013, and relatively warm temperatures in December 2013 (Liu & Guo 2014). The effects of weather can be seen in the variance of temperatures between 2012-2013 and 2013-2014 (Fig. 5 (B) and (C)). In particular, decreased rainfall in the spring and frost damage during the jointing and boot stages affected grain weight and number in 2012-2013 (Shen 2013).

5. Effects of tillage and residue management on grain yield

The MT_m treatment produced the greatest number of wheat panicles in 2013-2014 (Table 3). The panicle number per hectare, grain number per panicle, thousand grain weight, and panicle weight did not respond uniformly to the four tillage treatments in both years; however, the differences were not significant between all treatments in 2012-2013 ($P < 0.05$). Grain yield (7,608 kg/ha^{-1}) under MT_m treatment in 2013-2014 was significantly (19.5%) higher than that under FT_r treatment, but only slightly and not significantly higher than the yield under FT_i treatment. Similarly, wheat grain yield was slightly, but not significantly higher under CT than under traditional tillage in a wheat-sunflower crop rotation system in southern Spain (Moreno et al. 1997). Likewise, Arshad and Gill (1997) reported that reduced tillage produced a greater wheat yield than conventional or NT based on three years of experiments in northwestern Alberta. The beneficial effects of mulch may be associated with increased soil moisture (Triplett et al. 1968) and Raper et al. (2000) observed the positive effects of mulch on crop yield. López and Arrúe (1997) believed that adverse environmental conditions could easily influence seed growth, whereas Unger (1984) found tillage management using the greatest amount of residue had little effect on surface conditions.

The beneficial effect of minimum tillage and mulch residue on wheat grain yield could be attributed to improved soil properties and infiltration rates, as well as improved conservation of soil moisture (Sharma et al. 2011). Sow et al. (1997) also concluded that soil strength would decrease with increased soil water content. Increased soil water content is closely associated with greater root length and densities under NT, along with mulch residue when compared with conventional tillage, and results in higher crop yield. López and Arrúe (1997) reported that a similar crop response between conventional and reduced tillage treatments and poor grain yield with no-tillage, which depended more on seasonal rainfall and, hence, on the effective soil water content. One hypothesis states that seedling growth and grain yield with high soil strength under CT would not be adversely affected when there is sufficient soil water content. The findings of Fernandez-Ugalde et al. (2009) supported this hypothesis, and showed that NT resulted in improved soil structural properties. This appears to be consistent with the results of our experiment in that MT_m treatment was higher in stored soil water (0-10 cm) during the growing season.

Conclusion

Results from our two-year experiment indicated that MT could be recommended as a viable alternative to FT for North China. In particular, the practice of MT_m allowed a 25-29% saving in the amount of irrigation water used during the growth cycle of winter wheat. In 2012-2013, MT_m with reduced irrigation produced the same wheat yield with conventional irrigation. In 2013-2014, wheat yield under MT_m with reduced irrigation was also the same as that under FT_i with conventional irrigation, and higher than that under FT_i with reduced irrigation. This same yield of MT with reduced irrigation gives us confidence to promote MT_m in farmers' fields, which should reduce the amount of water consumed for agriculture.

Acknowledgments

We wish to thank the Japan International Research Center for Agricultural Sciences and the Institute of Agricultural Resources and Regional Planning, Chinese

Table 3. Grain yield of wheat in wheat-corn double cropping systems under MT and FT with different types of residue management (2012-2013 and 2013-2014)

Year	Treatment	Panicle number (× 1000)ha^{-1}	Grain number /panicle	Thousand grain weight (g)	Panicle weight (g)	Yield kg ha^{-1}
2012-2013	MT_m	7152 ± 504	24.4 ± 0.7	33.2 ± 1.2	0.81 ± 0.02	5784 ± 366
	MT_r	7263 ± 519	25.4 ± 2.0	30.8 ± 1.1	0.78 ± 0.08	5658 ± 228
	FT_i	6631 ± 573	25.6 ± 2.6	32.7 ± 0.8	0.84 ± 0.10	5520 ± 176
	FT_r	6615 ± 433	24.7 ± 2.1	33.2 ± 0.6	0.82 ± 0.06	5395 ± 44
2013-2014	MT_m	6839 ± 758a	28.3 ± 1.6	39.5 ± 2.4	1.12 ± 0.11	7608 ± 347a
	MT_r	6772 ± 1115ab	26.1 ± 2.4	39.6 ± 2.0	1.04 ± 0.14	6920 ± 176ab
	FT_i	6133 ± 570ab	29.1 ± 3.0	42.0 ± 0.9	1.22 ± 0.11	7460 ± 149a
	FT_r	5375 ± 879b	28.3 ± 2.8	42.3 ± 0.9	1.20 ± 0.09	6369 ± 584b

Values with different letters are significantly different among treatments each year (P<0.05) and those without letters are not (P<0.05).

Academy of Agricultural Sciences for their financial support and funding of this research.

References

Alvarez, R. & Steinbach, H. S. (2009) A review of the effects of tillage systems on some soil physical properties, water content, nitrate availability and crops yield in the Argentine Pampas. *Soil Till. Res.*, **104**, 1-15.

Arshad, M. A. & Gill, K. S. (1997) Barley, canola and wheat production under different tillage-fallow-green manure combinations on a clay soil in a cold, semiarid climate. *Soil Till. Res.,* **43**, 263-275.

Cui, F. et al. (2014) Assessing biogeochemical effects and best management practice for a wheat-maize cropping system using the DNDC model. *Biogeosciences*, **11**, 91-107.

Dong, W. X. et al. (2007) The effect of minimum tillage and no tillage on growth and yield of winter wheat. *ActaAgriculturaeBoreali-Sinica* [In Chinese], **22**, 141-144.

Du, S. (2013) Present situation and countermeasures of water saving agriculture development in North China. *China Agricultural Technology Extension* [In Chinese], **29**, 43-44.

Fernandez-Ugalde, O. et al. (2009) No-tillage improvement of soil physical quality in calcareous, degradation-prone, semi-arid soils. *Soil Till. Res.*, **106**, 29-35.

He, J. et al. (2011) Soil properties and crop yields after 11 years of no tillage farming in wheat–maize cropping system in the North China Plain. *Soil Till. Res.*, **113**, 48-54.

Huang, M. et al. (2009) Effects of different tillage management on production and yield of winter wheat in dry land. *Transactions of the Chinese Society of Agriculture* [In Chinese], **25**, 50-54.

Kaspar, T. C. et al. (1990) Corn response to seed-row residue removal. *Soil Sci. Soc. Am. J.*, **54**, 1112-1117.

Kong, A. Y. Y. et al. (2009) Transitioning from standard to minimum tillage: Trade-offs between soil organic matter stabilization, nitrous oxide emissions, and N availability in irrigated cropping systems. *SoilTill. Res.*, **104**, 256-262.

Li, H. W. et al. (2007) Effects of 15 years of conservation tillage on soil structure and productivity of wheat cultivation in northern China. *Aust. J. Soil Res.*, **45**, 344-350.

Li, S. J. et al. (2008) Characteristics of Growth and Development of Winter Wheat under Zero-tillage in the North China Plain. *ActaAgronomicaSinica* [In Chinese], **34**, 290-296.

Liu, X. et al. (2014) Effect of different tillage managements on soli water, temperature and emergence rate in oat field. *Journal of Triticeae Crops* [In Chinese], **34**, 692-697.

López, M. V. & Arrúe, J. L. (1997) Growth, yield and water use efficiency of winter barley in response to conservation tillage in a semi-arid region of Spain. *Soil Till. Res.*, **44**, 35-54.

Mannering, J V. & Fenster, C. R. (1983) What is conservation tillage? *J. Soil Water Conserv.*, **38**, 140-143.

McMaster, G. S. et al. (2002) Soil management alters seedling emergence and subsequent autumn growth and yield in dryland winter wheat-fallow systems in the Central Great Plains on a clay loam soil. *Soil Till. Res.*, **65**, 193-206.

Moreno, F. et al. (1997) Soil physical properties, water depletion and crop development under traditional and conservation tillage in southern Spain. *Soil Till. Res.*, **41**, 25-42.

Pan, X. Y. et al. (2011) Probabilistic modelling of soil moisture dynamics of irrigated cropland in the North China Plain. *Hydrologsci. J.*, **56**, 123-137.

Peng, W. Y. (2010) Study on dynamic change of soil moisture content under no-till in Beijing. *Workshop on communication of water-saving agricultural technology innovation and biological water-saving* [In Chinese], 251-256.

Qin, H. L. et al. (2006) Effect of plough and conservation tillage on soil moisture in ecotonebetween agriculture and animal raising of North China. *Journal of Arid Land Resources and Environment*, **20**, 166-170.

Raper, R. L. et al. (2000) Tillage depth, tillage timing, and cover crop effects on cotton yield, soil strength, and tillage energy requirements. *Appl. Eng. Agric.*, **16**, 379-385

Sharma, P. et al. (2011) Impact of tillage and mulch management on economics, energy requirement and crop performance in maize-wheat rotation in rain-fed subhumidinceptisols. India. *Eur. J. Agron*, **34**, 46-51.

Shinners, K. J. et al. (1994) Effects of residue-free band width on soil temperature and water content.*T. Asae*, **37**, 39-49.

Sow, A. A. et al. (1997) Tillage and residue effects on root growth and yields of grain sorghum following wheat. *Soil Till. Res.*, **44**, 121-129.

Su, Z. Y. et al. (2007) Effects of conservation tillage practices on winter wheat water-use efficiency and crop yield on the Loess Plateau, China. *Agr. Water Manage.*, **87**, 307-314.

Sun, D. L. et al. (2014) Meteorological index of freeze injury for tomato in 'shouguangwudai'greenhouse and its temporal change characteristics in the middle of Hebei province. *Journal of Meteorology and Environment* [In Chinese], **30**, 106-112.

Triplett, G. B. et al. (1968) Effect of corn (*Zea mays* L.) stover mulch on no-tillage corn yield and water infiltration. *Agronomy Journal*, **60**, 236-239.

Unger, P. W. (1978) Straw mulch effects on soil temperatures and sorghum germination and growth. *Agron. J.*, **70**, 858.

Unger, P. W. (1984) Tillage effects on surface soil physical conditions and sorghum emergence. *Soil Sci. Soc. Am. J.*, **48**, 1423-1432.

Uri, N. D. (1997) Conservation tillage and input use. *Environ Geol.*, **29**, 188-201.

Van den Putte, A. et al. (2010) Assessing the effect of soil tillage on crop growth: A meta-regression analysis on European crop yields under conservation agriculture. *Eur. J. Agron*, **33**, 231-241.

Xie, R. Z. et al. (2007) The analysis of conservation tillage in China-conservation tillage and crop production: Reviewing the evidence. *ScientiaAgriculturaSinica* [In Chinese], **40**, 1914-1924.

Zhang, H. et al. (1999) Water-yield relations and water-use efficiency of winter wheat in the North China Plain. *Irrigation Science*, **19**, 37-45.

Zhang, X. Y. et al. (2003) Conserving groundwater for irrigation in the North China Plain. *Irrigation Science*, **21**, 159-166.

Zhou, X. X. et al. (2001) Experimental study on conservation tillage system in areas of two crops a year in the North China Plain. *Transactions of the Chinese Society of Agriculture* [In Chinese], **17**, 81-84.