

Yuecun MA, Hongling QIN, Chunmei YIN, Wangsheng GAO, Hongsheng ZHANG, Peng SUI, Yuanquan CHEN, Xiangdong LI

Dynamics of soil water content under different tillage systems in agro-pastoral eco-zone

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Abstract The dynamics of soil water content under different tillage systems was studied throughout the growing period of oat (*Avena sativa* L.). The treatments included tillage system (zero tillage, minimum tillage, and conventional tillage), residue cover (with and without cover), and crop rotation (continuous cropping and crop rotation). The results indicated that soil water content and crop water use efficiency were improved under zero tillage with cover. When crop stubble was removed, soil water content under zero tillage was reduced, especially in the surface soil layer. Compared to conventional tillage, minimum tillage increased soil water content and its storage, either with cover or without cover. For all the three tillage treatments, soil water content with cover was significantly higher than that of without cover. Furthermore, soil water content and crop water use efficiency under crop rotation was consistently higher than continuous cropping. Therefore, it is concluded that minimum tillage with cover is the optimum management system in this area. At present, however, a combination of crop rotation and minimum tillage is a viable option, since there are not enough crop residues available for cover of land.

Keywords agro-pastoral eco-zone, conservation tillage, soil water content, cover

1 Introduction

The strategic importance of the agro-pastoral eco-zone to China is widely recognized (Gao, 2004). But being short of

Translated from *Acta Ecologica Sinica*, 2007, 27(6): 2523–2530 [译自: 生态学报]

Yuecun MA, Hongling QIN, Chunmei YIN, Wangsheng GAO (✉), Peng SUI, Yuanquan CHEN, Xiangdong LI
Center for Regional Agricultural Research & Development, College of Agronomy and Biotechnology, China Agricultural University, Beijing 100094, China
E-mail: wshgao@cau.edu.cn

Hongsheng ZHANG
Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, Shijiazhuang 050021, China

water, sustainable development of local agriculture is awfully restricted. Lots of studies have shown that conservation tillage is one of the effective measures by which soil water content and water use efficiency can be increased significantly in arid and semiarid regions (Willis and Bond, 1971; Lafond et al., 1992; Arshad et al., 1995). The main reasons are that zero tillage with crop cover can increase water penetration and reduce soil water evaporation so that soil moisture is conserved (Achary et al., 1998; Baumhardt and Jones, 2002; Carter, 1996). These results are similar to that of Liebig et al. (2004), Ferreras et al. (2000) and Olaoye (2002). There have also been many pertinent studies in China (Jia et al., 2002; Wang et al., 2005; Liao et al., 2002; Li et al., 2005), but most of the early studies were based on straw cover. However, in the agro-pastoral eco-zone in North China, little mulch from the former crop under zero tillage was left before sowing in the next year due to strong winds and cattle grazing. So it is very necessary to study the relationship between soil water, zero-tillage and minimum tillage without cover.

The objectives of this study were as follows: (1) working out the characteristics of soil water content under zero-tillage and minimum tillage in a semi-arid agro-pastoral eco-zone; (2) confirming the trend of soil moisture between rotation cropping and continuous cropping under the same tillage method; (3) confirming the trend of soil moisture between with cover and no cover under the same tillage method. Accordingly, the dynamics of soil water content was studied systematically, taking tillage, soil cover and rotation into account.

2 Methods

2.1 Study site

This study was conducted at the experimental station of China Agricultural University (41°05'N, 111°26'E), located in Wuchuan county of Inner Mongolia, in the middle part of the agro-pastoral eco-zone, with an area of 4885 km² and a population of 171000. The topography

was classified as hilly with mountains accounting for 41.9%, and hills for 50.4%. The flood land only accounted for 7.7% of the total area. The elevation ranges from 1600 m to 2000 m. The annual average temperature is 2.5°C; the highest average temperature occurs in the month of July (19.0°C). Annual precipitation is about 300 mm and is concentrated in May to September. The precipitation in 2006 was obviously deficient (Table 1). The frost-free period is about 105 days.

Table 1 Statistics of total rainfall during the whole development stage of oat in 2005 and 2006(mm)

year	May	Jun	Jul	Aug	Sep	total
2005	38.38	14.00	38.25	72.20	50.19	213.02
2006	30.57	33.44	73.57	17.52	0	155.1

2.2 Experimental designs

The study was conducted in a long-term field experiment initiated in 2003 in Wuchuan county, Inner Mongolia. The area of the experimental field was 0.36 hm² with the tested soil of castanozems. The soil texture was loamy (0–30 cm), chestnut colored (40–60 cm), and sandy loam (70–100 cm). Three factors were tested: tillage system (conventional tillage, zero-tillage and minimum tillage); residue cover (with and without cover); and crop rotation (continuous cropping and rotation cropping). The tested crop was oat (*Avena sativa* L.). There were six treatments in the experiment: minimum tillage under rotation cropping (MTR), zero-tillage under rotation cropping (ZTR), conventional tillage under rotation cropping (CTR), minimum tillage under continuous cropping (MTC), zero-tillage under continuous cropping (ZTC), and conventional tillage under continuous cropping (CTC). Three repetitions were designed for each treatment with a plot area of 0.02 hm² each. The former crop in rotation cropping had pea (*Vicia sativa* L.) as fodder.

As supporting experiments, the treatments MTR, ZTR, MTC and ZTC were performed in subplots with cover. Therefore, there were 4 sub-treatments of minimum tillage under rotation cropping with cover (MTRC), zero-tillage under rotation cropping with cover (ZTRC), minimum tillage under continuous cropping with cover (MTCC), zero-tillage under continuous cropping with cover (ZTCC). Each treatment was performed in three repetitions with a plot area of 15 m².

2.3 Experimental field management

Oat was planted without irrigation all year round. Weeds were controlled by herbicides, and all of the fertilizers used in the experiment were applied as basal at the rates of 15.9 kg·hm⁻² urea, and 17.61 kg·hm⁻² diammonium

phosphate, respectively. Oat straws were used to cover the plots to get a rapid increase in soil temperature and fast growth of oat in early spring when oat plantlets were just emerging.

2.4 Soil water measurement

Water content at each soil depth was measured gravimetrically and was expressed in percentage on an oven-dried basis. Soils were sampled to the depth of 100 cm in 10 cm increments at the time of pre-sowing, seedling, tillering, flowering, milking and post-harvest. The soil samples were weighed soon after they were taken to the laboratory, then oven dried at 105°C for 12 hours for dry weights. Finally, their gravimetric water contents were calculated.

2.5 Data analysis

The means from three replicates for each treatment were recorded for all the parameters measured. Differences among the treatments were determined using the method of least significant difference (LSD) test at the $P < 0.05$ level.

3 Results

3.1 Dynamics of soil water content under different tillage

3.1.1 Dynamics of soil water content under zero-tillage and minimum-tillage without coverage

3.1.1.1 Soil water content under different tillage at the pre-sowing stage

Figure 1 shows the comparison of soil water contents at the depth of 100 cm between different tillage systems at the pre-sowing stage. Under rotation cropping, soil water content at a depth of 100 cm for minimum tillage of the plot without cover was higher than that of conventional tillage, with significant difference from the layer below 20 cm. However, there was no significant difference for the top 20 cm layer. As for zero tillage without cover, soil water content at the depths of 0–10, 20–30, 30–40, 40–50 cm were 8.7%, 6.9%, 21.4%, 11.8% higher than that of conventional tillage, respectively. However, soil water content of zero-tillage without cover was insignificantly lower than that of conventional tillage in other soil layers (Fig. 1 a).

The same trend of soil water content was found for continuous cropping and rotation cropping (Fig. 1 b). Soil water content at 0–50 cm under minimum tillage without cover was higher than that of conventional tillage

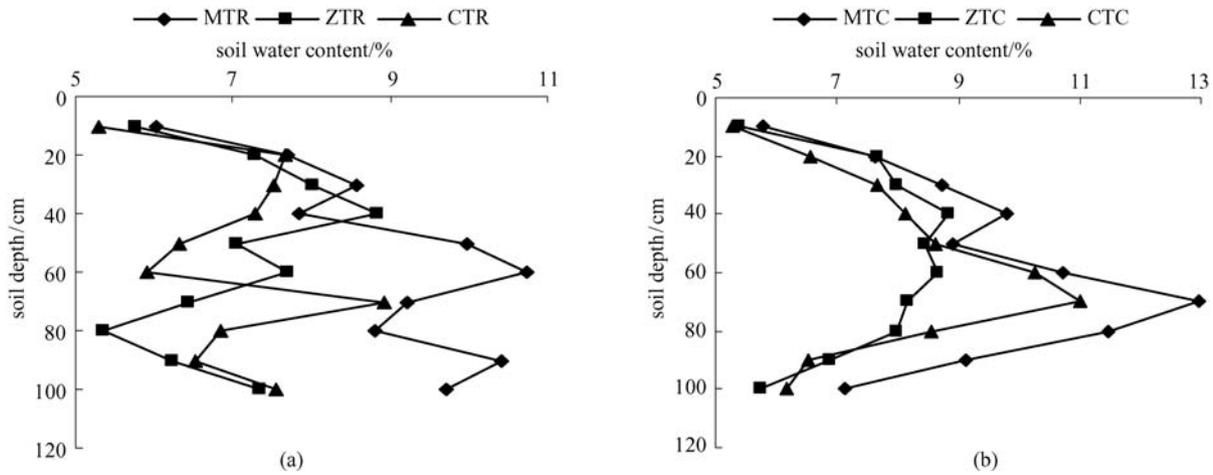


Fig. 1 Comparison of soil water content between different tillage systems at pre-sowing stage in 2006

Note: (a) Comparison of soil water content between different tillage with rotation at pre-sowing stage in 2006; (b) Comparison of soil water content between different tillage with continuous cropping at pre-sowing stage in 2006.

while at the layer of 50–100 cm, they were lower than that of conventional tillage. This result was due to lack of cover during the winter fallow period, when underground water rose to the surface layer through capillary action. Because of the large evaporating power of soil water, soil water content in the deep layer was lower compared to that of conventional tillage and higher than that of conventional tillage at shallow layers. However, soil water at deep layer was conserved under conventional tillage because of capillary disturbance.

3.1.1.2 Soil water content under different tillage at seedling and tillering stages

Figure 2a illustrates soil water contents at 100-cm-depth profile at seedling stage. Generally, soil water content under zero tillage and minimum tillage were higher than that of conventional tillage under rotation cropping. Soil

water contents at the depth of 0–10, 10–20, 20–30, 30–40, 40–50 cm under minimum tillage were 41.75%, 9.29%, 7.95%, 0.32% and 39.72% higher than that of conventional tillage, respectively. As for zero tillage, soil water content at the upper layer (0–50 cm) was lower compared with conventional tillage while higher at the deep layer (60–100 cm). Soil water content at 0–10, 10–20, 20–30 and 40–50 cm with zero-tillage were 14.97%, 17.33%, 16.95% and 10.33% lower, respectively, than that of conventional tillage but insignificantly higher (3.79%) at the layer of 30–40 cm. However, soil water content at the deeper layers of 50–60, 60–70, 70–80, 80–90, 90–100 cm were 18.72%, 11.37%, 3.25%, 18.50% and 14.17% higher (significant), respectively than in conventional tillage. Figure 2b shows the same results among the three tillage systems under continuous cropping.

A similar pattern of soil water content under different tillage systems was found at tillering. It is observed that

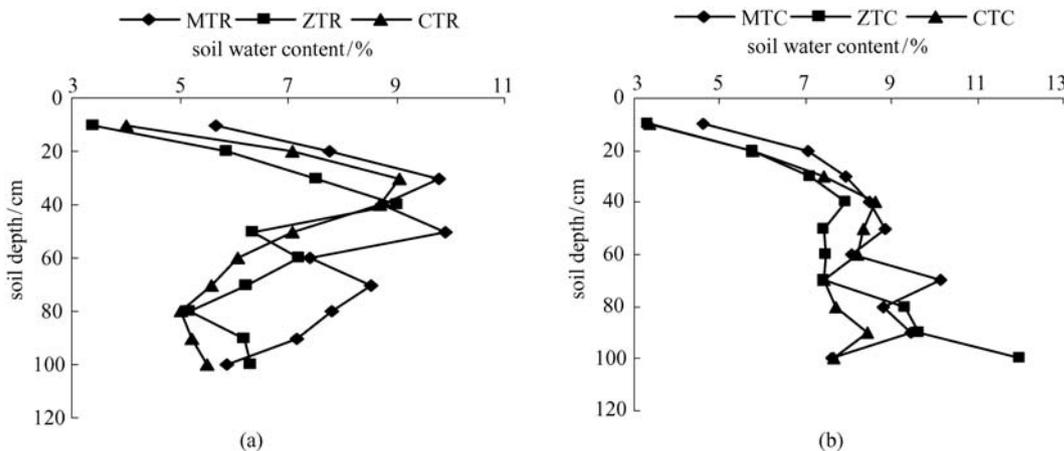


Fig. 2 Comparison of soil water content between different tillage systems at seeding stage in 2006

Note: (a) Comparison of soil water content between different tillage with rotation at seeding stage in 2006; (b) Comparison of soil water content between different tillage with continuous at seeding stage in 2006.

whether under rotation cropping or continuous cropping, soil water contents of minimum tillage without cover were always higher than that of conventional tillage, while under zero tillage soil water content in the upper layer was insignificantly lower, but higher in the deeper layer than in conventional tillage, either for rotation or for continuous cropping.

3.1.1.3 Soil water content at flowering stage

For rotation cropping, Fig. 3a shows that unlike the former two growth periods, soil water content at the upper soil layer under zero-tillage without cover was higher than that of conventional tillage, with increases of 10.35%, 1.64% and 1.08% at 0–10, 10–20, 20–30 cm, respectively compared with that of conventional tillage at flowering stage. Soil water content of layer 30–70 cm was lower and that below 70 cm was higher than that of conventional tillage. As for minimum tillage, soil water content at 100 cm layer was higher than that of all the other two tillage systems for corresponding soil layers. The same results for rotation cropping were observed for continuous cropping (Fig. 3b). One reason is flowering of oat is the threshold stage when oat needs to consume much water. Oat grew much better under conventional tillage so that water consumption was by far more than that of zero tillage, which led to soil water content under conventional tillage being lower than that of zero tillage at upper layers (Table 2).

3.1.1.4 Soil water content after harvest

For rotation cropping, soil water content for zero/minimum tillage without cover and conventional tillage after harvest was compared and shown in Fig. 4a. Soil water content of the profile at the depth of 100 cm under minimum tillage was higher than that of conventional tillage.

For zero tillage, compared with conventional tillage, soil water content at the depth of 0–10, 10–20, 20–30 cm was 1.47%, 9.27% and 14.88% higher, respectively. However, soil water content at 30–40, 40–50, 50–60 cm depth was 9.52%, 11.51% and 2.16% lower, respectively. Like other growth periods, soil water content of the deep soil layer under zero tillage was higher than that of conventional tillage, increased by 28.64%, 74.33%, 50.40% and 6.39%, respectively, for the soil layers at 60–70, 70–80, 80–90 and 90–100 cm.

A similar trend was found under continuous cropping (Fig. 4b). By effectively intercepting rainwater and reducing soil water evaporation, soil water content under minimum tillage was the highest of all the three tillage patterns. However, evaporation under zero tillage without cover was the biggest one. Therefore, in the early growth period, soil water content of the upper layer was lower than that of conventional tillage. However, in later growth period, because of much better growth conditions, soil water content under conventional tillage was lower compared with zero tillage. As far as deep soil layer was concerned, soil water content for zero tillage was higher than that of conventional tillage in the whole growth period.

3.1.2 Comparison of soil water content between zero/minimum tillage with cover and conventional tillage

At tillering stage of oat, soil water content of 0–100 cm layer under zero/minimum tillage with coverage was higher than that of conventional tillage (He et al., 2006). For continuous cropping, Fig. 5a shows that, compared with conventional tillage, soil water content of 0–10, 10–20, 20–30 cm layers under zero tillage was 14.48%, 22.93%, 20.4% higher than that of conventional tillage, respectively. As for minimum tillage, they were 29.49%, 45.05%, 28.15% higher than that of conventional tillage, respectively. For

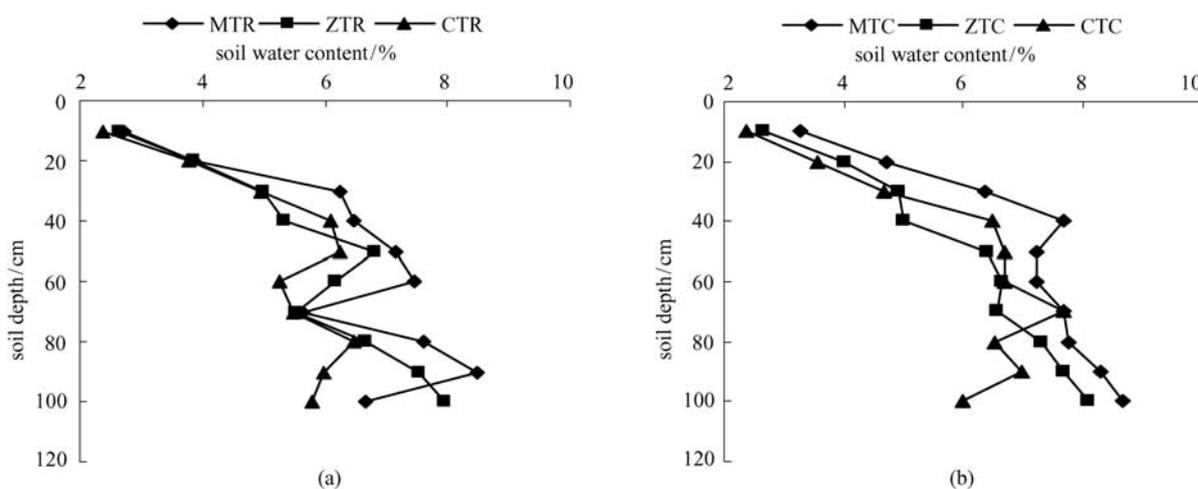


Fig. 3 Comparison of soil water content between different tillage systems at flowering stage in 2006

Note: (a) Comparison of soil water content between different tillage with rotation at flowering stage in 2006; (b) Comparison of soil water content between different tillage with continuous cropping at flowering stage in 2006

Table 2 Comparison of biomass of oat under different tillage systems at flowering in 2006

treatment	fresh weight/g		plant height/cm
	root	stem	
CTC	4.75c	50.55a	44.25a
ZTC	2.45d	16.1d	28d
MTC	5.45b	25c	39.53c
CTR	6.3a	45.55a	41.43b
ZTR	4.5c	25.35c	38.68c
MTR	5.7b	36.15b	40.21bc

Note: Different letters denote significant at $P < 0.05$ level.

rotation cropping (Fig. 5b), soil water content of 0–10, 10–20, 20–30 cm layers under minimum tillage was higher 64.1%, 8.9%, 1.2% than that of conventional tillage, respectively. For zero tillage, they were 42.9%, 20.5%,

14.7% higher than that of conventional tillage, respectively. They shared the same trend both at tillering stage and at flowering stage between coverage and the conventional tillage systems (Su et al., 2004) (Fig. 6).

3.2 Comparison of soil water content for different cropping patterns under the same tillage

3.2.1 Soil water content of continuous cropping and rotation cropping

Soil water content of continuous cropping and rotation cropping under minimum tillage is shown in Table 3. Soil water content of the top soil layers under rotation cropping was higher than that of continuous cropping in periods of pre-sowing, seedling, and tillering, while it was

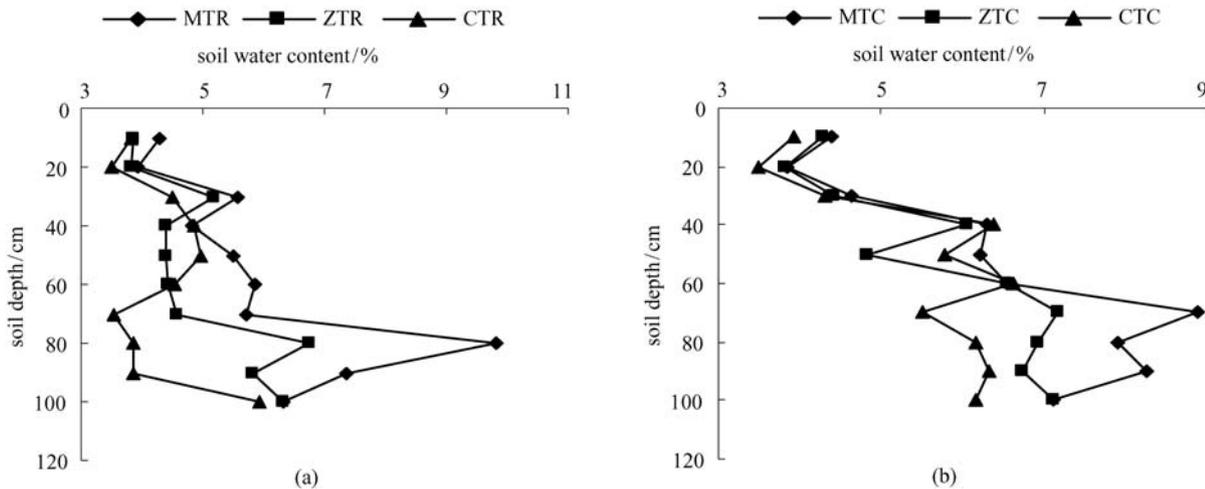


Fig. 4 Comparison of soil water content between different tillage systems after harvest in 2006

Note: (a) Comparison of soil water content between different tillage with rotation after harvest in 2006; (b) Comparison of soil water content between different tillage with continuous cropping after harvest in 2006.

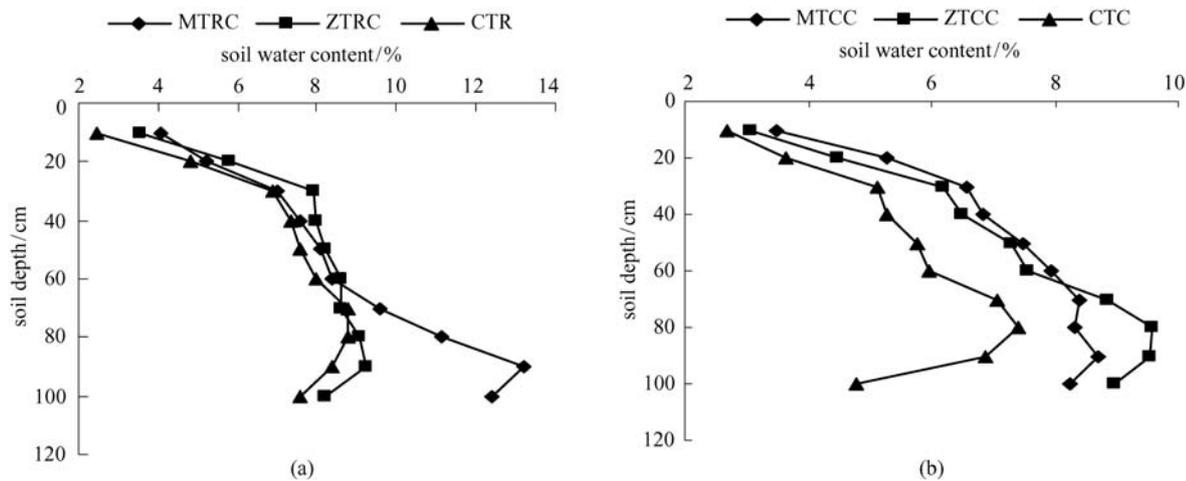


Fig. 5 Comparison of soil water content of ZT/MT with cover and conventional tillage between different tillage systems at tillering in 2006

Note: (a) Comparison of soil water content of ZT/MT with cover and conventional tillage under rotation at tillering in 2006; (b) Comparison of soil water content of ZT/MT with cover and conventional tillage under continuous cropping at tillering in 2006.

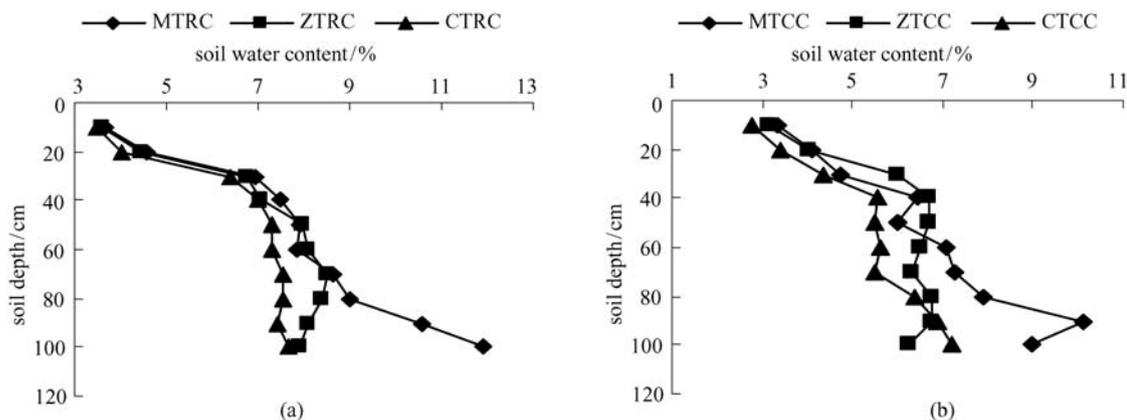


Fig. 6 Comparison of soil water content of ZT/MT with cover and conventional tillage between different tillage systems at flowering stage in 2006
 Note: (a) Comparison of soil water content of ZT/MT with cover and conventional tillage under rotation at flowering stage in 2006; (b) Comparison of soil water content of ZT/MT with cover and conventional tillage under continuous cropping at flowering stage in 2006.

Table 3 Soil water content of rotation and continuous cropping under minimum tillage in 2006 (%)

soil depth/cm	pre-sowing		seedling		tillering		flowering		post harvest	
	MTR	MTC	MTR	MTC	MTR	MTC	MTR	MTC	MTR	MTC
0–10	5.40*	5.30	3.40	3.37	5.14	5.08	2.72*	2.65	4.27*	4.39
10–20	7.28*	6.55	5.87	5.75	6.68	5.84	3.79*	4.02	3.85	3.93
20–30	8.57*	7.65	7.54*	7.12	6.81*	5.60	4.94	4.66	4.30*	4.51
30–40	8.83	8.11	8.73*	8.51	7.14	6.22	5.33*	5.02	4.40	4.49
40–50	7.06*	8.89	6.35*	8.86	6.64*	8.83	6.83*	6.70	4.97	4.82
50–60	7.68*	10.74	7.39*	8.06	6.35*	9.07	7.46	6.71	4.53*	6.55
60–70	6.43*	12.96	8.52*	10.16	7.53*	9.27	5.49*	7.67	4.02*	7.17
70–80	5.35*	11.47	7.83*	8.83	7.68*	9.04	6.65*	9.31	–	6.92
80–90	4.54*	9.12	7.15*	9.47	7.37*	9.08	7.53*	7.69	–	8.26
90–100	3.50*	7.14	5.51*	7.62	5.69*	9.01	7.29*	6.00	–	6.16

Note: * denotes significantly different at $P \leq 0.05$.

lower than that of continuous cropping in the deep soil layers. However, compared with continuous cropping, soil water content of rotation cropping decreased from flowering to harvest. After harvest, soil water content in the soil layers of 0–10, 10–20, 20–30 and 30–40 cm under rotation cropping was 2.67%, 1.96%, 4.68% and 1.99% lower than continuous cropping, respectively. This resulted mainly from a much better growth of oat under rotation cropping which lead to a higher water consumption by the crop under rotation cropping.

During its whole growth period, soil water content of rotation cropping in deep soil layer was lower than that of continuous cropping. For the layers of 40–50, 50–60, 60–70, 70–80, 80–90, 90–100 cm, soil water content was decreased by 28.37%, 8.25%, 16.07%, 11.33%, 24.51% and 27.7%, respectively, compared with continuous cropping. In a word, the soil water content of the upper layer under rotation cropping in early growth periods was higher than continuous cropping, but lower than continuous cropping in later growth periods of the crop. However, in deep layers, soil water content under rotation cropping was lower than that of continuous cropping for the whole growth period.

Table 4 shows that, unlike minimum tillage, there were different trends for zero tillage. In the 0–40 cm layer, soil water content under rotation cropping was higher than that of continuous cropping during the whole growth period of oat, which resulted from low water consumption of the crop due to its bad growth, both under rotation cropping and continuous cropping.

Table 4 Soil water content of rotation and continuous cropping under zero tillage during whole growing stage of oat in 2006 (%)

soil depth/cm	pre-sowing		seedling		tillering		flowering		post harvest	
	ZTR	ZTC	ZTR	ZTC	ZTR	ZTC	ZTR	ZTC	ZTR	ZTC
0–10	5.77*	5.27	4.00	3.31	4.86	4.56	2.39	2.35	3.94	3.87
10–20	7.68	7.67	7.10*	5.76	5.99	5.87	3.85*	3.55	3.51*	3.50
20–30	8.03	7.97	9.08*	7.40	7.55*	6.22	6.24*	4.94	5.58*	4.42
30–40	7.83*	8.84	9.03*	7.93	7.12	7.42	6.51	6.11	4.84*	5.06
40–50	9.97*	8.45	9.89*	7.41	7.35*	9.16	7.15	6.41	5.49	6.22
50–60	10.73*	8.65	7.20	7.48	7.75	8.33	5.27*	6.64	5.85	6.56
60–70	9.11*	8.15	6.23*	7.43	7.12*	7.41	5.53*	6.56	–	5.51
70–80	8.81	7.98	5.19*	8.20	6.17	6.74	6.49*	6.55	–	6.16
80–90	10.25*	6.88	5.21*	8.15	5.12*	7.23	5.99*	7.00	–	6.33
90–100	8.52*	5.75	6.29	–	4.47*	8.88	7.96*	8.09	–	7.11

Note: * denote significantly difference at $P \leq 0.05$.

In deep layers, soil water content under rotation cropping was also lower than that of continuous cropping in the whole growth period. This was caused by the intensive water consumption by the well developed root system of oat under rotation cropping.

3.2.2 Soil water content impacted by cover

Table 5 shows soil water content status of both the covered and normal plots under zero tillage together with rotation cropping. In all the soil layer tested, soil water content of mulch covered plots was significantly higher than that of bare ones, especially for the 0–50 cm cultivated layer, which is very crucial for oat growth in arid regions. This trend also existed for other tillage methods. The result indicated that, compared with tillage, mulch cover played a more important part in increasing soil water content.

Table 5 Soil water content of mulch covered and bared plots under zero tillage in different growing stages of oat in 2006 (%)

soil depth/cm	flowering		milking		harvest	
	ZTRC	ZTR	ZTRC	ZTR	ZTRC	ZTR
0–10	3.53*	2.39	3.79	3.47	5.83*	3.87
10–20	5.79*	3.85	4.01	4.02	4.80*	3.51
20–30	7.91*	6.24	6.39*	4.66	5.66	5.58
30–40	7.96*	6.11	7.01*	4.55	6.34*	4.84
40–50	8.21*	7.15	7.32*	3.93	6.38*	5.49
50–60	8.59*	5.27	7.28*	4.16	6.56*	5.85
60–70	8.62*	5.53	7.52*	4.8	6.58*	5.71
70–80	9.06*	6.49	7.56*	5.18	6.74*	6.21
80–90	9.25*	5.99	7.42*	5.81	6.13	5.81
90–100	8.17	7.96	7.66	7.55	6.99*	6.32

Note: * denote significant difference at $P \leq 0.05$.

4 Discussion

4.1 Influence of zero/minimum tillage without cover on soil water content

Our results indicated that, by an all year round dynamic observation, soil water content under minimum tillage without mulch was significantly higher than that of conventional tillage. However, there was no significant increase in soil water content for zero tillage without mulch, especially in cultivated layer; soil water content under zero tillage without mulch was lower than that of conventional tillage. However, soil water content beneath the cultivated layer was higher than that of conventional tillage. The main reason was attributed to the intense evaporation and low precipitation in agro-pastoral ecozones. The capillary water was disturbed by conventional ploughing, thereafter water evaporation was reduced to a certain extent while the evaporation under zero tillage was obviously accelerated than conventional tillage because of

less soil disturbance and free cover. Having the advantages of conventional tillage and zero tillage, minimum tillage effectively intercepted rainfall, and water-holding capacity was enhanced so that soil water content under minimum tillage was the highest.

4.2 Influence of zero/minimum tillage with cover on soil water content

Soil water contents of both zero tillage and minimum tillage with straw cover, especially for minimum tillage, were significantly higher than that of conventional tillage because evaporation was decreased greatly under mulching, which was very important for crop growth and yield.

4.3 Difference of soil water content between continuous cropping and rotation cropping

Soil structure and water-holding capacity were improved to a large extent (Huang et al., 2003), so during the earlier growth period of oat, soil water content of the upper layers under rotation cropping was significantly higher than that of continuous cropping regardless of the tillage method. However, in later growth period, water consumption of oat under rotation cropping was significantly higher than that of continuous cropping. As a result, insignificantly, soil water content under rotation cropping was lower than that of continuous cropping. In deep soil layers, soil water content under rotation cropping was lower than that of continuous cropping throughout the whole growth period, which was also closely related to the growth condition of oat.

4.4 Influence of coverage on soil water content

In all the soil layers tested, water content in soil covered with mulch was significantly higher than that of bare soil whether in zero or minimum tillage. This result was consistent with other researches. Our result showed that the effect of mulch cover on soil water conservation was superior to zero tillage and minimum tillage. The key reason why conservation tillage could increase soil water should be attributed to mulching (Michels et al., 1995).

From the above results and analysis, adoption of conservation tillage depends on how the local farmers solve the problem of mulching, which was the key factor to increase soil water content. Theoretically, minimum tillage with cover under rotation cropping was the optimal mode of conservation tillage, but when there is a shortage of covering materials, minimum tillage under rotation cropping was more practical to the local farmers.

Acknowledgements This project was funded by the National Eleventh Five-year Project, China (No. 2006BAD15B00). We thank the Inner Mongolia Academy of Agriculture Science for providing us all that we

needed in the experiment. We also thank Professor Tuo Debao, associate professors Zhao Peiyi and Duan Yu for their help in managing the experimental plots and sample collection. We are also grateful to the hard work of all the technicians who assisted us in the field.

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