Research on the effect of straw mulching on the soil moisture by field experiment in the piedmont plain of the Taihang Mountains

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Abstract: To reveal the influencing effect of the long-term straw mulching on the soil moisture, this paper employed the field experiment data in 2010 of a typical area of Taihang Mountains plain, observed the soil moisture dynamic regularities under different mulching patterns by virtue of depressimeter and neutron probe, analyzed the characteristics of soil water content and storage in different depths and seasons under the long-term straw mulching. The results showed that the long-term straw mulching can keep the soil moisture conservation of the deep, while decreased the shallow. (1) The long-term straw mulching can changed the type of soil water movement. If no straw mulching, the type is mainly evaporation-infiltration. And with straw mantle the type would change into infiltration. The number of zero flux plane would be reduced or absent. (2) The long-term straw mulching can increase the soil water reserves of the whole soil profile with the depth between 0 cm and 220 cm. But the soil water content of the layer from 30 cm to 80 cm decreased and the soil water content of the layer from 80 cm to 220 cm increased instead., The effect of soil moisture conservation on winter wheat is not obvious; (3) With no straw mulching, the depth of infiltration recharge by rainfall or irrigation is shallower than 80 cm. In a straw mulching, the influence depth is can extend to 120 cm; (4) With no straw mulching , there is a deep layer on the depth of 220 cm between March and June, while this layer will disappear with a long-term straw mulching.

Keywords: Straw mulching; Soil moisture; Soil water content; Deep layer; Soil moisture conservation

Introduction

The earth's critical zone, which was initiated by the U.S. National Research Council (NRC) in 2001, is the intersection zone where pedosphere has material migration and energy exchange with atmosphere, biosphere, hydrosphere and lithosphere in the earth surface system, and the key zone which guarantees the earth's ecosystem functions and the human survival (NRC, 2001). Because water and soil are the key components of the earth's critical zone, the research on water and soil can solve some scientific problems in the earth's critical zone (Hayden E C, 2015; Berdugo M *et al.* 2014). Soil moisture is the key factor in the critical zone of piedmont plain of Taihang Mountains in North China and the determinant for the growth of plain vegetation and the sustainable development of local agriculture. Precipitation in the piedmont plain of Taihang Mountains is highly uneven in that surface water is almost exhausted and groundwater level continues to decline. As a result, the serious shortage of water resources has become a major inhibitor to the development of agriculture (XIA Jun, 2002). The soil water technology is one of the important ways to alleviate the crisis of water for agricultural purpose (JIN Meng-gui *et al.* 2006). Straw mulching is one form of soil water technology. Star mulching means that the crop

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straws or their breakable objects are used to cover the surface of arable soil evenly so that the soil of arable land is exposed to less sunlight or rainfall erosion. In this way, the precipitation infiltration rate can be increased and the soil moisture conservation can be achieved.

In recent years, China has seen some benefits through its persistent efforts to introduce some agricultural water conservation measures like straw mulching. Many scholars have conducted different researches into the effect of straw mulching on soil moisture. ZHAO Xiao-feng and other scholars conducted the large-scale experiment on the wheat and corn straw mulching technology of dry cropland in Shanxi Province to explore the effect of straw mulching on the soil moisture of arid crop. The experiment showed that the straw mulching technology used in arid and semi-arid regions can play a positive role in many ways and especially contribute much to soil moisture conservation and soil melioration and fertilization (ZHAO Xiao-feng and ZHAO Fang-ming, 2007). ZHOU Ling-yun and other scholars conducted the experiment on straw mulching of cropland in Shangqiu, Henan Province. The experiment revealed that the straw mulching technology used in wheat cropland can noticeably reduce water-consumption coefficient and ground evaporation between plants, conserve water for irrigation and increase the utilization efficiency of water resources (ZHOU Ling-yun *et al*. 1999). WANG Bing-guo and other scholars used Luancheng experiment station as a case to analyze how straw mulching technology affects soil moisture of cropland. The study proved that straw mulching, in spites of its negative effect on the infiltration recharge from rainfall and irrigation water, can restrain the non-available evaporation of soil moisture and increase the utilization rate of soil moisture (WANG Bing-guo *et al*. 2010). After a sufficient analysis was made of the systematic errors between trial point and control point of straw mulching, WU Qing-hua explored the laws of dynamic changes of soil water when soil is covered by corn straws and pointed out that straw mulching can only exert a small effect on the dynamic change of soil moisture in the depth of 180 cm and below (WU Qing-hua *et al*. 2009). Now there are few studies on the effects of long-time straw mulching on the dynamic change of soil moisture. The data of this study were based on the comparison and analysis of the dynamic characteristics of soil moisture in trial point and control check zone after straw mulching for eight years to gain an insight into the differentiation change of soil water movement after the long-term straw mulching.

1 Study background and experiment overviews

1.1 Overviews of study zone

The field experiment was conducted in Luancheng experiment station of Shijiazhuang Institute of Agricultural Modernization of Chinese Academy of Sciences. This experiment station is located in Luancheng County, Shijiazhuang in the heart of piedmont plain of Taihang Mountains. With the flat terrain, the experiment station falls within the temperate continental monsoon climate zone, which features the clear distinction of four seasons, namely dry and windy spring, hot and rainy summer, cool autumn, and cold and less snowy winter. Its annual temperature averages 12.8 ℃, and its annual precipitation 474.0 mm. Rainfall mainly happens during the period from July to September, which accounts for more than 70% of the annual precipitation.

There is no source of surface water within study zone, and the water for agricultural irrigation mainly depends on groundwater. The aeration zone is rather thick and its thickness increases from 10 m (in 1975) to 37 m (in 2010) (WU Qing-hua *et al*. 2012). The groundwater level continues to fall, and the infiltration from precipitation and irrigation water constantly recharges groundwater, and dynamic characteristics of shallow soil water are hardly affected by groundwater regime. This paper focused on the dynamic characteristics of shallow soil water. The shallow soil mainly consists of loam, light clay loam and clay loam in terms of soil texture. Table 1 provides the properties of tested soil within the depth of 0-210 cm.

1.2 Experiment methods

1.2.1 Field experiment setup

To conduct the check experiment on straw mulching, this study selected two trial points with the same crops plants and irrigation system, and with the similar soil lithology. The corn growth period falls between the mid-June and the early October, and the winter wheat growth period falls between the mid-October and the mid-June the next year.

Table 1 Properties of tested soil

Soil depth (cm)	Soil texture	Volume weight (g/cm^3)	Specific weight (g/cm^3)	Porosity	Field moisture capacity (v/v)	Wilting moisture (v/v)	Saturated hydraulic conductivity (m/d)
0-25	Loam	1.387	2.72	0.4925	36.35	9.63	1.090
25-40	Loam	1.497	2.73	0.4610	34.86	11.37	0.434
40-60	Loam	1.465	2.72	0.4640	33.25	13.92	0.730
60-85	Loam	1.488	2.73	0.4623	34.28	13.91	0.713
85-120	Light clay loam	1.537	2.75	0.4573	34.36	12.95	0.020
120-165	Clay loam	1.628	2.77	0.4233	38.98	13.87	0.003
165-210	Light clay loam	1.553	2.75	0.4373	38.05	16.44	0.016

(Sources: Luancheng Experiment Station, Center for Agricultural Resources Research, Institute of Genetics and Development Biology of Chinese Academy of Sciences)

Depressimeter system and neutron probe were installed in two trial points separately to monitor soil water potentials and soil water contents. Besides, rain gauge and irrigation meter were prepared within the experiment field to measure the quantity of precipitation and irrigation respectively. Two trial points were defined as No. 1 trial point and No. 2 trial point separately. The first one is the trial point of straw mulching and the second one is the control point of non-straw mulching.

The installation position of depressimeter and neutron probe is indicated in Fig. 1. Depressimeter was WM-1 mercury depressimeter system developed by Geological Institute of Hydrogeological Environment of Chinese Academy of Geological Sciences, and the neutron probe was Britain's 1H-II neutron moisture gauge. Depressimeter and neutron moisture gauge shared the same observation depth. Within the depth of 100 cm, one observation point was arranged for every 10 cm. Within the depth of 100-260 cm, one observation point was arranged for every 20 cm (WU Qing-hua *et al*. 2009).

Observation time: one regular observation on three-day basis; more frequent observations in case of precipitation or irrigation, such as once an hour at the beginning, once two-four hours later, and gradually a bigger interval of observations until the regular observation time is resumed.

In the straw mulching experiment, the corn straws with the length of 2-3 cm were used to cover the trial point No.1 and the observation time started from the year 2003. This paper selected the experiment data in 2010.

1.2.2 Data analysis method

Soil water content means the volume of soil water contained in the unit-area soil column above the potentially usable depth of crops and between two depths in aeration zone. The total soil water content means the volume of soil water contained in the unit-area soil column above the potentially usable depth of crops. Like the actual storage of surface water reservoir, the total soil water content can be used to measure the quantity of soil water. Abbreviated as W, it is indicated as mm. Numerically, the soil water content is equal to the integration of distribution coefficient θ of soil volumetric water content within the depth of d1-d2, and the integration of total soil water content falls within the scope of 0-d. specifically, d is the potentially usable depth of crops. Water content and total water content are indicated by W and Wt separately.

$$W(t)=\int_{d1}^{d2} q(z,t)dz\text{，}\quad W_t(t)=\int_0^d q(z,t)dz \qquad (1)$$

2 Result and analysis

2.1 Comparative analysis of the type of soil water movement during different periods

The type of soil water movement within the study zone mainly took the form of evaporation-infiltration (LI Man *et al*. 2014). To analyze the effect of straw mulching on the soil water movement, the graphs of total soil water potentials with different conditions of straw mulching during different periods were used to conduct the comparative analysis.

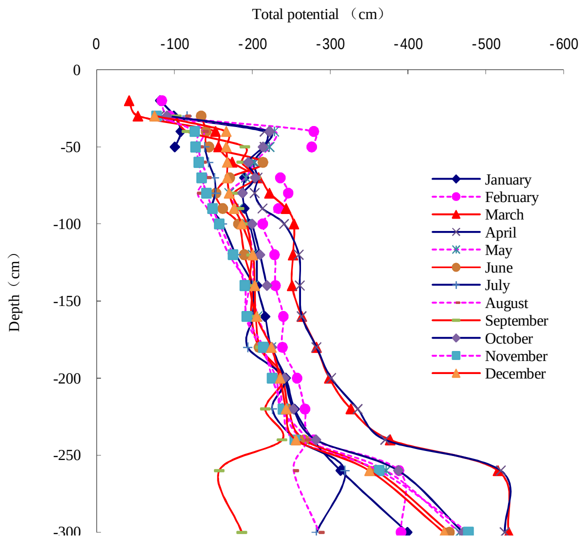


Fig. 1 Graph of total soil water potentials with no straw mulching during different periods

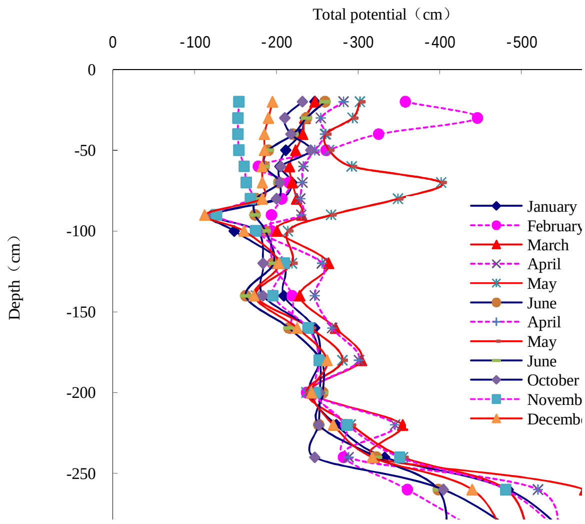


Fig. 2 Graph of total soil water potentials with straw mulching during different periods

With no straw mulching type, the type of soil water movement mainly took the form of evaporation-infiltration type. With multiple zero flux planes, the total soil water potentials showed the noticeable changes over time above the depth of 0-100 m. The soil moisture at this depth basically moved upward. With straw mulching, the type of soil water movement mainly took the form of infiltration. The zero flux planes decreased significantly and even finally disappeared. The total soil water potentials showed less noticeable changes over time above the depth of 0-100 m. The soil moisture basically moved downward. Therefore, long-term straw mulching led to some changes to the type of soil water movement in trial point from evaporation-infiltration type to infiltration type. Based on the test data during the early stage of straw mulching in this trial point, the analysis revealed that the short-term straw mulching did not change the type of soil water movement in that the type of soil water movement in two trial points were both evaporation-infiltration type (WU Qing-hua *et al*. 2009). So the long-term straw mulching caused a radical change to the dynamic characteristics of soil moisture in the trial point.

To conclude, the long-term straw mulching changed the type of soil water movement from evaporation-infiltration type to infiltration type, and caused the zero flux planes to decrease and even disappear. The straw mulching could effectively inhibit the surface evaporation so that the soil water movement close to the ground surface was changed from evaporation type to infiltration type.

2.2 Analysis of soil profile moisture characteristics during different periods

The dynamic change of soil moisture is vulnerable to the effects from precipitation conditions, climate, crop growth and soil texture, but straw mulching is likely to change the effects of these factors on the soil water movement. During their research on the effects of straw mulching on precipitation infiltration, LIU Li-jing pointed out that straw mulching could delay the infiltration of rainwater, but for the precipitation of different strength, straw mulching produced effects to different degrees (LIU Li-jing *et al*. 2004). When ZHAO Xiao-feng examined the effect of straw mulching on the soil moisture of arid cropland and proposed that straw mulching played a noticeable role in soil moisture conservation to raise the utilization rate of natural precipitation significantly (ZHAO Xiao-feng and ZHAO Fang-ming, 2007). ZHU Zi-xi proposed that straw mulching could change the water consumption characteristics of crops (ZHU Zi-xi *et al*. 2000). When the dynamic changes of soil moisture with straw mulching was studied, WU Qing-hua pointed out there were some systematic errors in soil volumetric water contents and water potentials within two trial points, and identified some patterns. He also mentioned that the effects of straw mulching on soil water movement were mainly related to the precipitation conditions, climate, precipitation growth, soil depth and initial water contents of soil (WU Qing-hua *et al*. 2009).

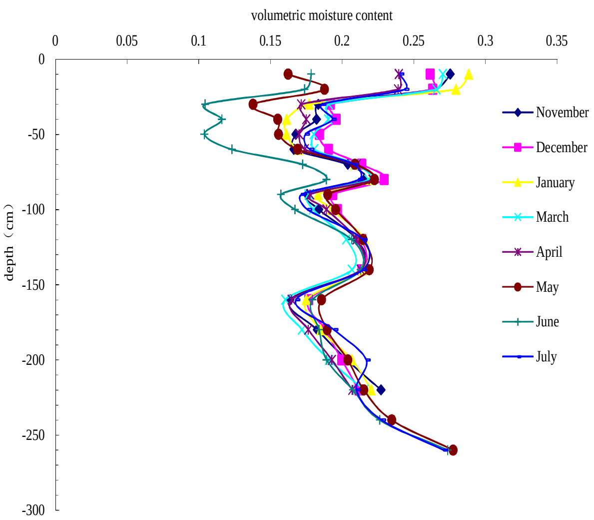


Fig. 3 Comparison of soil profile moisture contents ratio with straw mulching during different months

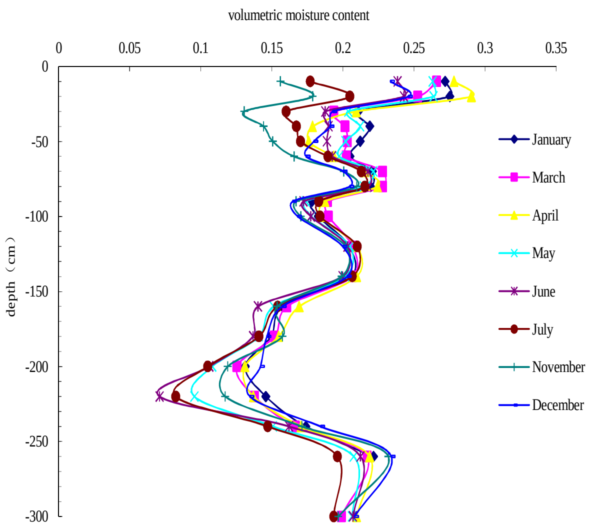


Fig. 4 Comparison of soil profile moisture contents ratio with straw mulching during different months

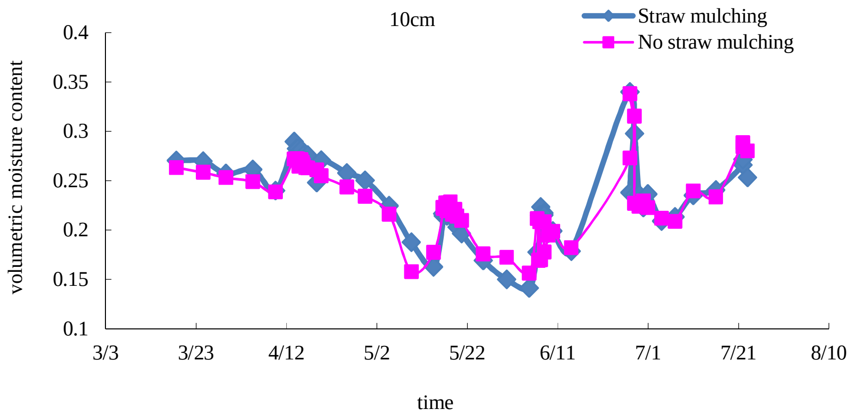
The comparative analysis of the changes in soil profile moisture contents with straw mulching and with no straw mulching during different months shows that straw mulching can strengthen the effects of such external factors as precipitation, irrigation and evaporation on soil moisture content. With no straw mulching, the effect of external factors is usually shallower than 80 cm. With straw mulching, the effect of external factors is as deep as 120 cm. With no straw mulching, soil moisture during the period from March to June sees a clear low-moisture layer at the depth of 220 cm. With straw mulching, this low-moisture layer disappears. It is probably because that the dynamic characteristics of water moisture experiences some changes after the long-term straw mulching experiment. The deep soil gets constantly recharged through infiltration so that water moisture contents at this depth continues to increase. The long-term straw mulching can determine how the characteristics of deep water moisture change and contribute to the deep soil moisture reservation.

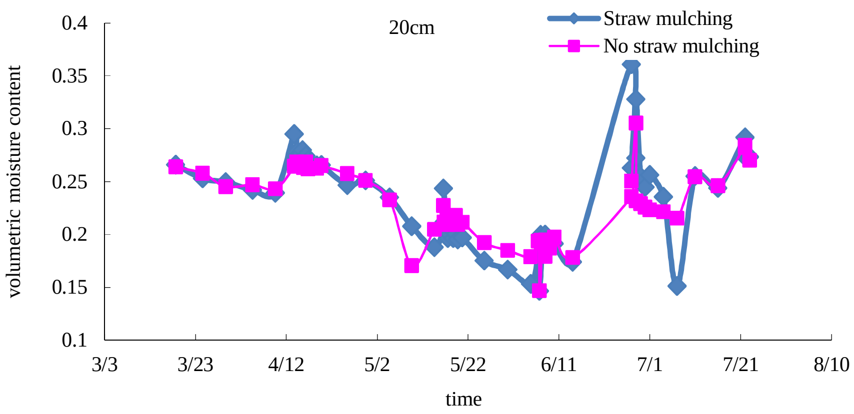
2.3 Comparative analysis of soil moisture characteristics at different depths

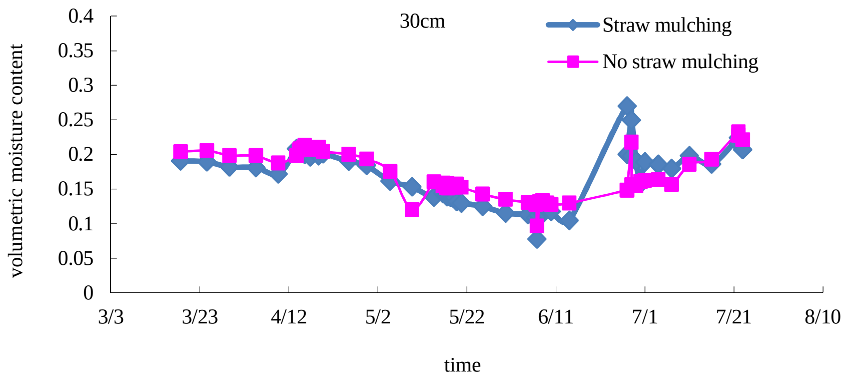
The change in soil moisture content at different depths and under different conditions during the growth period of winter wheat (March to July 2010) is used to analyze the comparative curve of soil moisture content at eight depths including 10 cm, 20 cm, 30 cm, 60 cm, 80 cm, 100 cm, 160 cm and 200 cm (as indicated in Fig. 2).

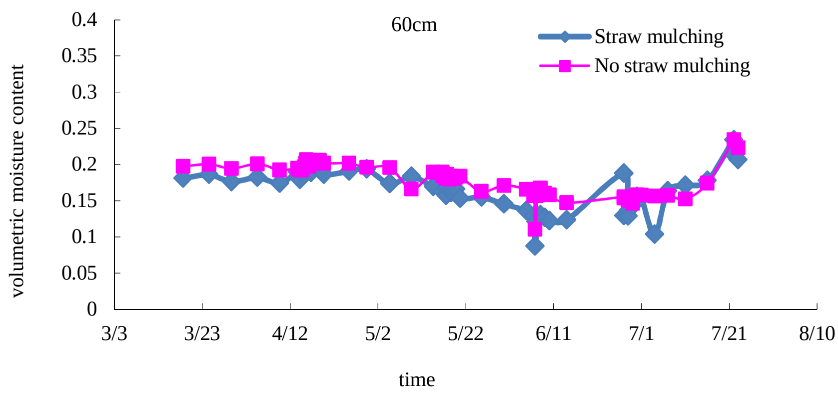
The curve-based comparative study shows that the soil layer can be divided into three segments including 0-30 cm, 30-80 cm and 80-200 cm when the divergent changes of soil moisture contents with straw mulching and with no straw mulching is taken into consideration.

Within the depth of 0-30 cm (refer to the curve-based comparison of 10 cm and 20 cm), curves with straw mulching and with no straw mulching are almost the same. And water moisture contents are considerably affected by the changes of external effects. There is a very small difference within the period from May to July. So the straw mulching exerts a limited effect on the shallow soil moisture content at the depth of 20 cm. Some meager effects can be noticed only when there’re some major changes to external conditions like precipitation or evaporation.









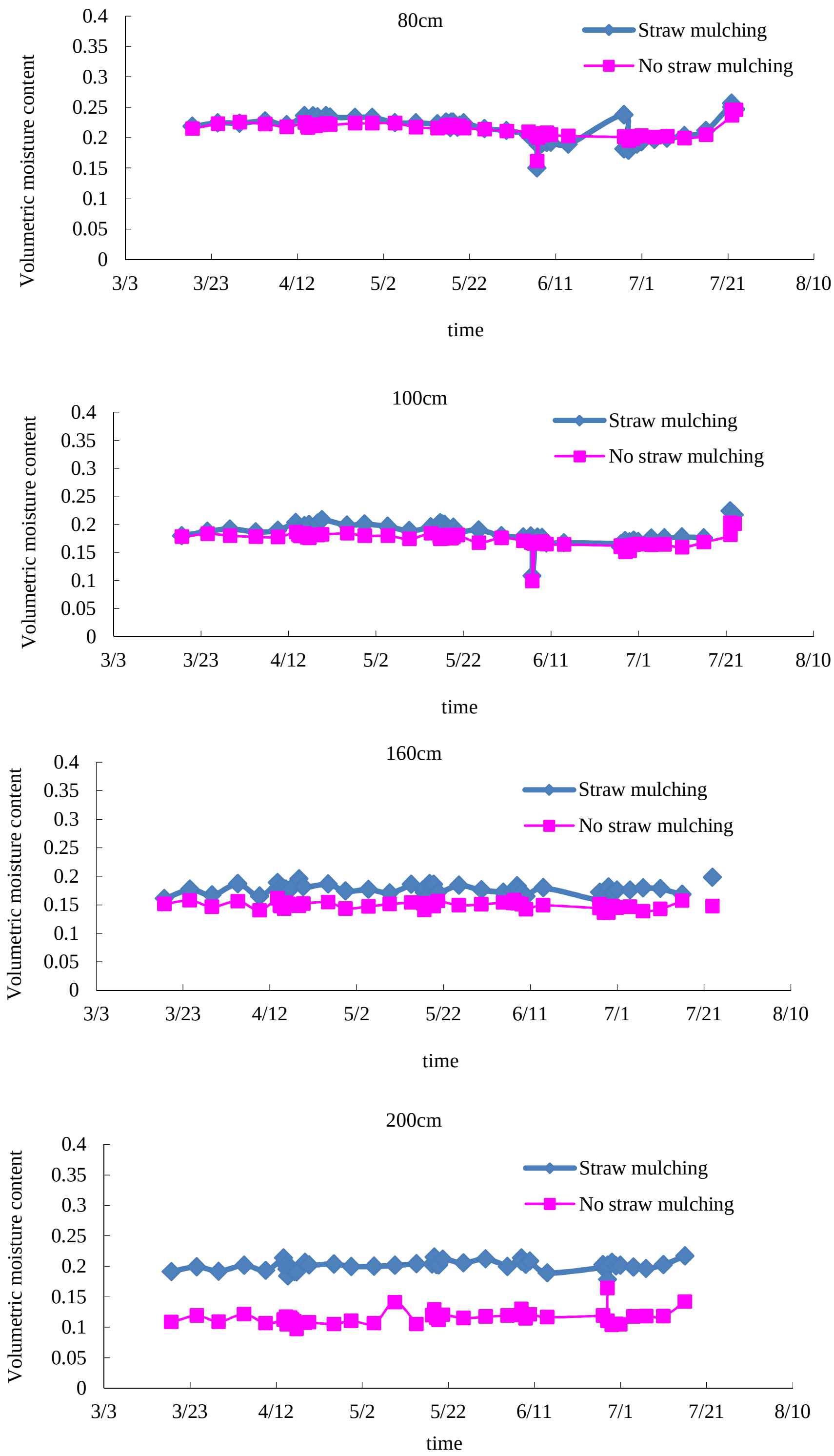


Fig. 5 Curve of soil moisture content with no straw mulching at different depths

Within the depth of 30 cm to 80 cm (refer to the curve-based comparison of three depths like 30 cm, 60 cm and 80 cm). Difference decreases along with the increasing depth when the soil moisture content with no straw mulching is slightly bigger than with straw mulching. A the depth of 80 cm, two curves tends to overlap. Therefore, the soil moisture content at this depth is considerable when there is no straw mulching. It is because the straw mulching reduces the precipitation infiltration at this depth.

Within the depth of 80 cm to 200 cm, the soil moisture content with straw mulching will gradually get bigger along with the growing depth than with no straw mulching. In other word, straw mulching contributes to the soil moisture conservation at this depth.

To conclude, the long-term straw mulching exerts a limited effect on the soil moisture content at the depth of 30 cm. The straw mulching turns out to reduce the soil water recharged through infiltration within the depth of 30 cm to 80 cm. With the increasing depth, the straw mulching gradually gets soil moisture content to become bigger within the depth of 80 cm to 220 cm than without straw mulching. Therefore, the long-term straw mulching can only conserve the soil moisture within the depth of 80 cm to 220 cm. But when it comes to the growth of winter wheat in the northern part of China, roots are mainly distributed within the depth of 0-100 cm, mostly within the depth of 0-50 cm (LIU Rong-hua *et al*. 2008). So the long-term straw mulching can contribute nothing to the soil moisture conservation of winter wheat.

2.4 Comparative analysis of soil water content within different soil layers

To further explore the effects of straw mulching on characteristics of soil moisture, the curves showing the changes in soil water contents at the depth of 0-220 cm, 0-30 cm, 30-80 cm and 80-220 cm were calculated separately. The growth period of winter wheat (March to June) was chosen as the time slot to conduct the comparative analysis as indicated in Fig. 3.

Within the whole soil profile (0-220 cm), the soil water content with straw mulching is much higher than with no straw mulching. Straw mulching can raise soil water content by 8%-20%. The long-term straw mulching will help increase the moisture of soil profile, thus playing a role of soil moisture conservation. For the shallow soil layer at the depth of 30 cm, soil water content remains almost the same whether with straw mulching or with no straw mulching. The long-term straw mulching imposes a limited effect on soil water content somewhere near the surface soil layer. For the soil layer within the depth of 30-80 cm, the soil water content is lower with straw mulching than with no straw mulching. In fact, the long-term straw mulching turns out to reduce soil water content in the soil layer of this depth range, specifically by 1% to 15%. For the soil layer within the depth of 80-220 cm, the soil water content is much higher with straw mulching than with no straw mulching. In fact, the long-term straw mulching increases soil water content in the soil layer of this depth range, specifically by 18% to 35%.

To conclude, the long-term straw mulching can increase the soil water content within the whole soil profile. The long-term straw mulching turns out to reduce the water soil content within the depth of 30-80 cm, but raise the water soil content within the depth of 80-220 cm.

3 Discussion and analysis

Many scholars have achieved different research findings concerning the effects of straw mulching on the dynamic characteristics of soil moisture. When a study was conducted on the effects of winter wheat straw mulching in the piedmont plain of the Taihang Mountains on the growth and soil moisture utilization of summer corns, CHEN Su-ying pointed out that star mulching could increase the soil water content within the depth of 0-60 cm and especially within the depth of 20-40 cm (CHEN Su-ying *et al*. 2002). When a study was conduct on WU Qing-hua explored the laws of dynamic changes of soil water with straw mulching in Luancheng experiment station and pointed out that straw mulching exerted the strongest effect on soil water content within the depth of 0-180 cm. But the increasing depth saw a weakened effect (WU Qing-Hua *et al*. 2009). WANG Hui studied the effect of straw mulching on summer corn yield and dynamic changes of soil water under the condition of super-high yield in Shandong Province. He pointed out that straw mulching could significantly increase the soil water content within the depth of 0-90 cm in the cropland (WANG Hui *et al*. 2011). BAI Xue-feng examined the effect of straw mulching on the dynamic changes of soil moisture in Songnen Plain, and pointed out that soil moisture content was higher with straw mulching than with no straw mulching and that soil moisture content was highest within the depth of 0-40 cm (BAI Xue-feng *et al*. 2014). However, these were only the preliminary research findings about straw mulching, and there was no analysis and discussion after the experiment on long-term straw mulching.

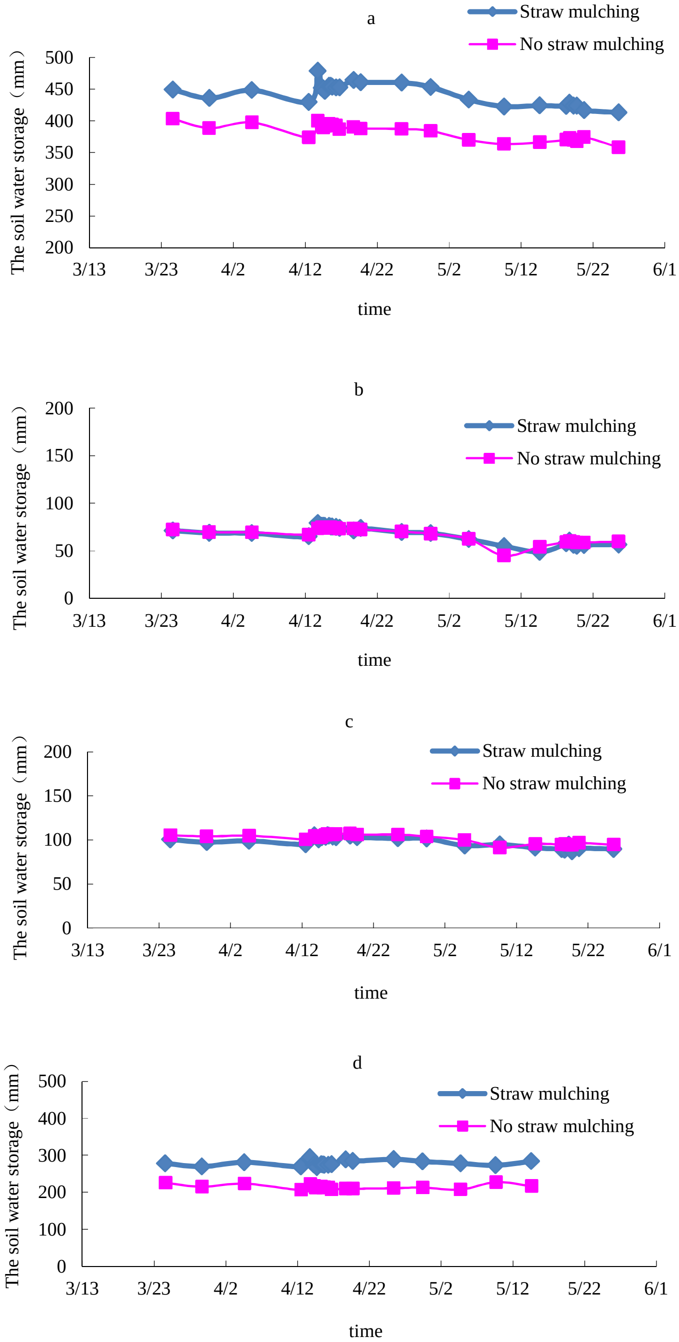


Fig. 6 Curve of comparative analysis of soil water content

a. Change curve of soil water content within the depth of 0-220 cm
b. Change curve of soil water content within the depth of 0-30 cm
c. Change curve of soil water content within the depth of 30-80 cm
d. Change curve of soil water content within the depth of 80-220 cm

The data used in this experiment were obtained after the eight-year straw mulching experiment in which the dynamic changes of soil moisture with straw mulching and with no straw mulching were compared, the characteristics of soil moisture and change of soil water content within different time slots and at different depths were examined, and the effects of long-term straw mulching on the characteristics of soil moisture were analyzed. The analysis and discussion are detailed as follows:

(1) The long-term straw mulching can cause a radical change to the dynamic characteristics of soil moisture in trial point. The type of soil water movement changes from evaporation-infiltration type to infiltration type. The number of zero flux plane will be reduced, and even get absent.

(2) The long-term straw mulching can increase the soil water content in trial point across the soil

plane. Specifically, the long-term straw mulching increases soil water content within the depth of 80-220 cm, but reduces soil water content within the depth of 30-80 cm. In other words, its role in soil moisture conservation is identified only in the depth soil layer. For the growth of winter wheat in the northern part of China, roots are mainly distributed within the depth of 0-100 cm, mostly within the depth of 0-50 cm. So straw mulching can’t play a role of soil moisture conservation for the soil layer of winter wheat roots.

(3) Straw mulching can strengthen the effects of precipitation, irrigation and evaporation on soil moisture content. In the trial point, the depth of effect is less than 80 cm with no straw mulching, but is as much as 120 cm with straw mulching.

(4) The long-term straw mulching can change the laws of variation of soil water characteristics and plays a bigger role in the soil moisture conservation of deep soil layer. With no straw mulching, there is a deep layer on the depth of 220 cm between March and June, while this layer will disappear with a long-term straw mulching.

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