

Study on Movement Evolution Law of Soil Water in Condition of Agronomic Water Saving Irrigation

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Abstract: Fresh water supplied are often limited in mainland China, reducing agricultural productivity. However the use of straw mulch is the main management technique for agronomic water saving. This paper investigates the movement of soil water under straw mulch compared to a non-mulch test plot. Results demonstrated that straw mulch effected soil water movement primarily during drought periods and throughout shallow soil (i.e. depths of less than 200 cm). The soil moisture and soil water potential at the mulch test plot in drought period are both higher than that of contrast test plot, and along with increasing soil depth, the straw mulch effect weakens. When evaporation is dominated by surface evaporation, straw mulch will effectively restrict the evaporation of soil water; when evaporation dominated by vegetation transpiration, the straw mulch promotes the transpiration of vegetation. In drought periods, straw mulch is not effective for deep soil water infiltration, but is advantageous for soil water utilization of mid- and shallow- soils (0-120 cm), however the infiltration speed rate of straw mulch point during high water period is higher than that of contrast plot. This paper highlights the importance of good management practices of agricultural land in order to limit soil water losses, which is essential when water is such a limited resource.

Key words: agronomic water saving; soil water movement; evolution law

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1. Introduction

Water is essential for human survival, and is the guarantee of social economic development. Along with industrial development and social progress, the demand for fresh water resources has

greatly increased, but surface water and shallow underground water have become seriously polluted, which greatly limits the supply of safe fresh water. In the Hebei Province of middle east China, agricultural water accounts about 83.5% of total

water consumption, highlighting the need solve this agricultural demand for water, which is key in reducing the demand on fresh water resources in this area, and promoting agricultural water saving measures is one of basic ways for resolving the supply and demand contradiction of agricultural water.

Water saving irrigation technology reduces water use by more effectively and efficiently using water, as opposed to traditional irrigation technology practices, by means of agronomic water saving practices. Agronomic water saving practices optimize the farm water use by the utilization of comprehensive agronomic technology measures, including mulch technology, cultivation technology, and water-allocating with fertilizing.

Ground mulch technique involves the application of a waterproof retaining layer to the ground surface. The mulch material reduces surface evaporation, thus reducing the amount of irrigation water required. In addition, mulching improves the soil temperature and water preservation, as well as reducing erosion via the rainfall impact, and thus maintaining the soil structure. Moreover, the straw mulch material is recycled into the soil after harvesting, prior to sowing the subsequent crops, therefore increasing soil organic matter (SOM), further improving soil structure, and promoting soil fertility.

Straw mulch is a low cost, locally available material which is convenient and produces no pollution, as a result, the use of mulching has gained much attention in recent years. Due to the economical benefits of mulching, this management practice has become one of the most frequently utilised and most convenient agronomic water saving methods used in mainland China.

It has important practical significance to research the evolution law of soil water movement under straw mulch. Indeed, research on the soil water movement under straw mulch has been

broadly covered in the literature from the effect of mulching on soil heat capacity and diffusivity (Li Chunyou et al. 2000), to the impact on water heat by straw decomposition (Douglas C L et al. 1992). Multiple researchers have investigated the effect of straw mulch on soil evaporation, soil temperature, soil water movement, and rainfall infiltration (e.g. Shen kairong et al. 1997), however none considered the systematic differences between straw mulch test and contrast test. Currently, the typical study depth for soil water movement under straw mulch is rather shallow, at ca 1 m, however the utilization depth of soil water of agricultural crops can reach to 2 m (Jin Menggui et al. 2006). As a result, this paper aims to build on previous research by investigating the deep soil water movement and underground water supply impact after straw mulch.

2. Materials and methods

2.1 Study area

The study area is located in Luancheng County, Hebei Province, middle east area of China, at the east foot of Taihang Mountain, and southeast of the capital city, Shijiazhuang ($37^{\circ}47'34''$ - $38^{\circ}01'07''$ N, and $114^{\circ}28'55''$ - $114^{\circ}47'35''$ E), with a total area of 379km^2 , see Fig. 1. The study area has a temperate continental climate with four distinct seasons. The temperature ranges from a high monthly average of 26.4°C in July, to a minimum monthly average of -3.7°C in January. Total yearly solar radiation is $5.3 \times 10^8 \text{ J/cm}^2$, with a yearly average sunlight of 2521.9 h. Influenced by monsoons and the Taihang Mountain, the study site has a variable yearly and season rainfall, with a change in rate of yearly rainfall of 26%. The average annual rainfall is 480.7 mm, of which more than 60% falls in July and August. However, the annual evaporation potential is 1092.3 mm, which exceeds that of rainfall, as a result irrigation is required in order to ensure high yielding crops.



Fig.1 The location of Luancheng County, North China

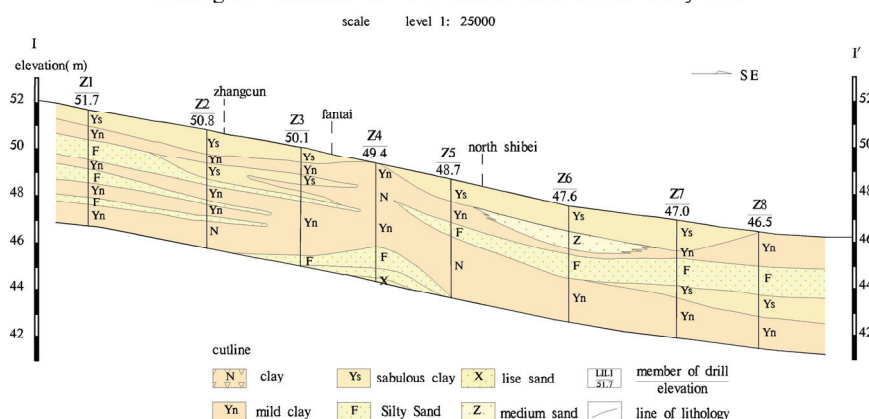
At present, the study area mainly exploits shallow ground water, (i.e. I and II aquifer, in which the I aquifer has been drained, and the II is a shallow buried micro artesian water aquifer, receiving water via rainfall, side supply, river infiltration and infiltration from well irrigation return water, which has a strong re-supply capacity, drainage mainly depends on manual exploitation, and side run-off). The deep ground water is located much deeper, and mainly receives water via a side supply from the west and northwest mountain area and transfluence supply from shallow water, and side drained in southeast.

The thickness of vadose zone in study area is 30 m, supplied by rainfall and irrigation water infiltration, the underground water level movement impacting on the shallow soil water movement. This paper focuses on the soil water movement in the vadose zone above 3.4 m. The lithological

character is primarily mild clay, bulldust, fine sand, and medium sand.

Fig. 2 illustrates the cross-section lithological character of the two vadose zones in the study area, at a depth of 5 m. Between the surface and 1 m, the soil is agricultural planting earth, which is very important for crop planting. The lithological character shown in Fig. 2 is mild clay, dark brown, developed in loess matrix of deluvial alluvial-proluvial fan. Due to the influence of warm temperatures in semi-humid conditions, the plain terrain in front of mountain and the hydrological conditions, the cinnamon soil and meadow cinnamon soil gradually evolved to become agricultural soils under long term farming. Between 1 m and 5 m, the soil is composed of mild clay, bulldust, with some areas containing fine/medium sand, and are brownish yellow.

lithological character of I-I vadose zone in the study area



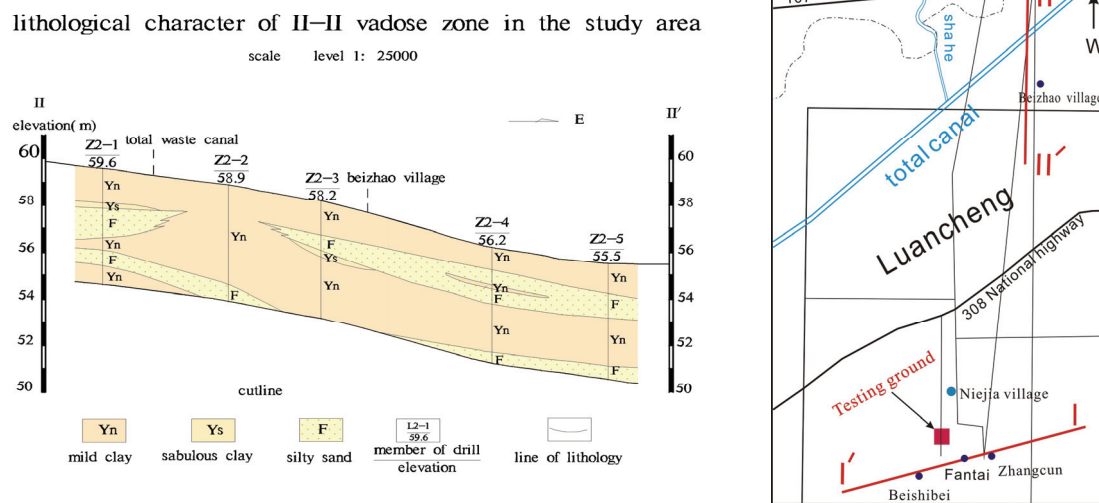


Fig. 2: Lithological character of the a) I-I vadose zone and b) II-II vadose zone in the study area

2.2. Test design

The field test was developed in the Luancheng testing field of Shijiazhuang Agricultural Modernization Institute of Chinese Academy of Science. The Luancheng test station was established in 1981, and joined the China Ecological System Research Network (CERN) in 1988, becoming a member of the Global Terrestrial Observing System (GTOS) in 1999, and later becoming a station of China Ecological Observing & Research Network (CEORN) in 2005.

This test selects two fields that are 50 m apart, located in the same lithological section, under the same crops, irrigation conditions, and similar soil lithological character, each field was separately equipped with two groups of tensiometers system, the two groups neutron catheter are separately used for monitor the soil water potential at section and water content, meanwhile set the rainfall barrel, irrigation water meter, and E601 to measure daily rainfall, irrigation volume of every time, daily evaporation amount at water surface.

The tensiometers adopts the WM-1 mercury tensiometers that was developed by the Hydrological Geology and Environmental Geology Institute of China Academy of Geological Science.

Every group was buried with 20 tensiometers, the maximum depth is 3.4 m. Every 10 cm set up one in depth of 1 m. In depth of 1-2.6 m, every 20 cm set up one, and in depth of 2.6-3.4 m, every 40 cm set one, which are installed in hidden bury and oblique cutting way. The observation room is semi-underground, in order to reduce conduct negative pressure and accordingly reduce bubble of water media, in addition to improving the currency of measuring results. This allows measurements to be taken below freezing point with the addition of anti-freeze fluid in the conducting media water, and then it can be continuously observed in the whole winter in north China. The observation time is every three days under regular rainfall, increasing to every half hour or one hour under heavy rainfall and irrigation events, in order to observe one time in initial period, then every 2-4 hours, 6-12 hours, and gradually add time distance.

The British IH-II neutron moisture meter was set up with each neutron tube placed ca.1 m beside every tensiometer group, at a depth of 3.4 m. The water content observing spot corresponds to every tensiometer, and have synchronous frequency. The calibration work was completed prior to neutron meter measuring.

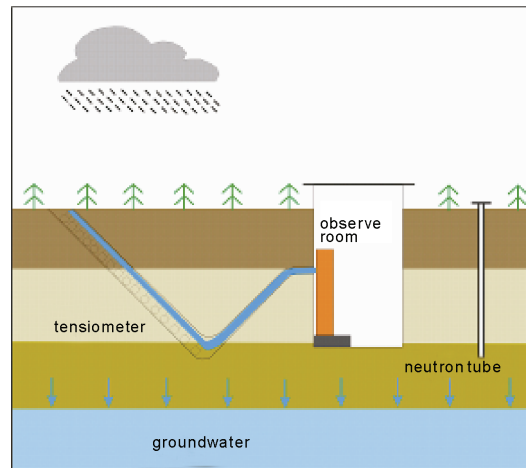


Fig. 3: Installation of tensiometers and neutron tubes

The testing period was carried out between April 2003 and September 2007, in which the period from December 4, 2003 to October 13, 2004 was used to develop the straw mulch test; in which straw were uniformly distributed at 2-3 cm thickness over an area of 20 m². This cover of 0.6kg/m² on the straw mulch test points, allows for the investigation into the soil water movement, and how this contrasts with the natural planting site.

3. Results and analysis

3.1 Systematic difference analysis of test

During the testing period, the difference of the observed soil water movement are caused by two parts: one of which is systematic error contained by the two test points, this kind of error is primarily from the soil structure, non-uniformity of soil space, testing error of apparatus, contact of tensiometer and soil, calibration error of neutron meter and artificial observing error; the second is error caused by the straw mulch. The purpose of this test is to research the impact of straw mulch on soil water movement, therefore it is important to remove the systematic error between the two test points from the observing documents during mulch testing period to accurately research the impact.

Through sufficiently analyzed the documents about soil movement before mulch test and two years after mulch test, this chapter found that there is certain regularity between soil water content and water potential of the two test points. The

difference of water content of the two test points is related to weather, rainfall and soil depth, with the difference decreasing as burial depth increases.. The difference is small in heavy rainfall or during irrigation, and larger in periods. In the shallow planting area (0-40 cm), the difference of soil water content has a distinguished discipline with time, the difference of the two water content has a jump around the last irrigation before Spring of every year, and decreases along with depth increase; the difference of soil content in 50-120 cm does not change with time; the different of soil content in 140-180 cm have distinguished discipline with time, but has no obvious jump range; the soil content in 200-340 cm has no relationship with time, and is stable throughout the year. In the mulch test period, use this discipline to separately calibrate the soil content of different depth, and make the soil content of the two test points in the same level as much as possible. However, the reading difference of tensiometer has not distinguished relationship with time, rainfall condition, and depth, after analyze data, it found that the difference has relationship with the reading dimension of the two tensiometers. The thesis divides the negative reading into six zones, namely 50-100 cm, 100-200 cm, 200-300 cm, 300-400 cm, 400-500 cm, and <500 cm, separately count the reading difference of negative pressure of every zone, calculate average value of every zone, and use this mean value to calibrate the soil water

potential in mulch test period through simple computer program.

3.2 Impact of straw mulch on soil water content movement

The monitoring information of soil water in the mulch test period shows that surface coverage influences the soil water content movement, and appears as a seasonal change feature. The water content slowly decreased from January to mid April, the water content largely increased after the first irrigation, then rapidly decreased, and reaches to the lowest level in early June. From early June to mid August, the water content continuously increases and reaches the annual highest level. From the mid August to late September, the soil water content tends to decrease in general, the water content has small fluctuation during these periods, which is mainly caused by the duration of water demand fluctuation of crops, irrigation, and rainfall. From late September to mid December, rainfall decreased rapidly and has no irrigation, the soil water content trends to decreasing. From late December to next middle January, the soil water content increased a little because of low temperature, weak solar radiation, tiny surface evaporation, and some snow melt.

The impact on soil water movement of mulch is related to the rainfall condition, climate, crop

growing status, and initial soil water content. From early January (2004) to late March (2004), the rainfall precipitation was only 9.3 mm, accounting for 2% of the annual rainfall, corresponding to the drought period and crop seedling period, whereby the soil water consumption is mainly soil evaporation, and the water content of mulch test exceeds that of the contrast point (Fig. 4) Figure 4 shows that the straw mulch has good preservation effect on soil water in drought period. From May to August of 2004, the rainfall precipitation was 390 mm, accounting for 76% of the annual precipitation, corresponding to the high water period, whereby the soil water consumption is primarily from crop transpiration. In this time, the crops grew well and had plentiful rainfall, only the soil water content of the straw mulch at 10 cm depth is higher than that of contrast point, the water content of the two test points of other monitor point are equal, and the straw mulch has little impact on soil water (Fig. 5).

The soil water movement varies with different depths, together with increasing soil depth, the impact degree on soil water movement of straw mulch is weaker until disappear. The impact of mulch on soil water movement is most apparent at a depth of 0-180 cm, whereas the soil water movement at a depth of 180 -340 cm is not influenced by surface mulch condition.

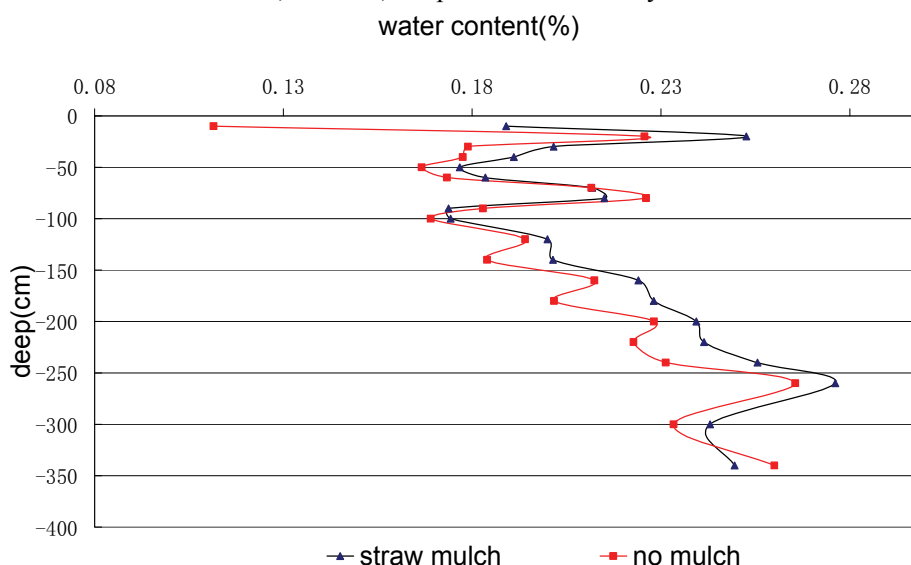


Fig. 4 Contrast of soil water content in drought period (3.20)

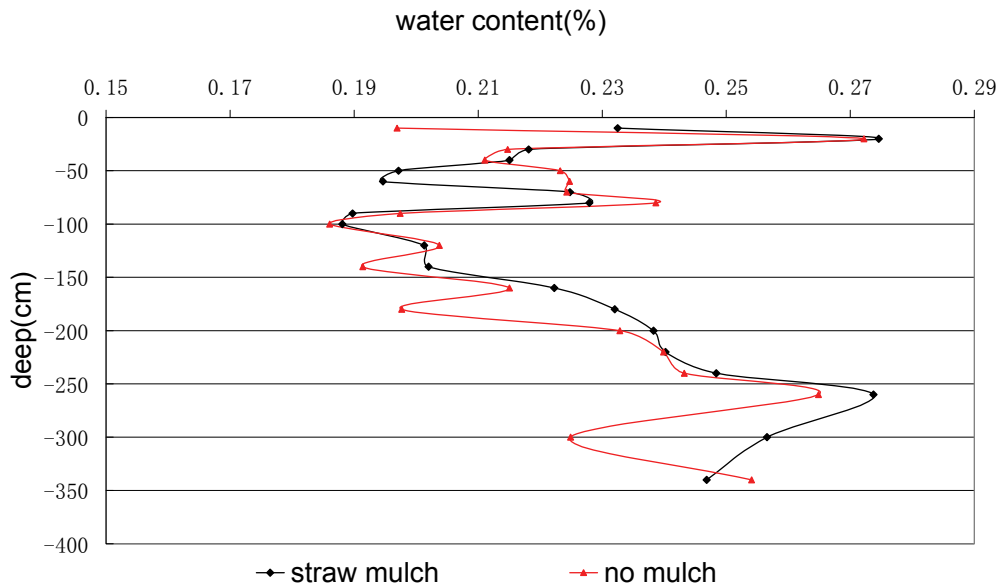


Fig. 5 Contrast of soil water content in high water period (7.14)

From January to April (2004) and September 2004 to April 2005, the water content at 10 cm depth at the two sites have the largest differences. This is primarily due to the initial period of crop growth, and the crops having little ground covering. The surface evaporation is mainly is soil evaporation; however straw mulch can reduce the degree of soil evaporation, resulting in a higher surface soil water content higher compared to that of the control plot.. During crop growth, the flourish leaves can completely cover the ground surface, minimizing direct solar radiation, therefore maintaining low soil temperatures. The straw mulch at this time has only a slight influence on the surface soil water content.

The response status for straw mulch at depths of 20 cm, 30 cm, and 40 cm soil water movement are basically conformity, and the influence extent decrease along with increasing of depth (Figs. 6, 7, 8). From the first irrigation in Spring to mid April, the soil water content of straw mulch points are higher than that of the control plot, which shows that straw mulch in these period has a water preservation function. Throughout the rest of the year, the water content at the two test points is equal.

At depths of 50 cm and 60 cm, the mulch test

points are lower than contrast test points from middle July to mid September (Fig. 9), showing that straw mulch does not affect deep soil water preservation in this period. The response to straw mulch at a depth range of 70 - 180 cm mainly occurs in January to April (2004) and April (2005) after the first irrigation to mid May (2005), the water content of the two test points in other time basically trends to conformity (Fig. 10). At a depth range of 180 - 340 cm, the soil water content is not affected by surface mulch conditions, and has small fluctuations throughout the year (Fig. 11).

3.3 Impact of straw mulch on soil water potential movement

From mid January to early April (2004) there is a drought period, the soil water potential in the covering test points is higher than that of contrast test points (Fig. 12), showing that the straw mulch can effectively prevent soil water movement to the ground surface (i.e. evaporation consumption). During May to June of 2004, the water potential of covering test point is again higher than that of contrast test point, which shows that straw mulch can effectively retain the soil water evaporation in the middle period of crop growth. Throughout 2004 and early June to late August of 2005, the

crops grew vigorously as a result of a high water period, and straw mulch has little effect on surface soil evaporation. Fig. 13 shows the soil water potential movement after a heavy rainfall (108 mm), water potential at 10 cm depth of the straw test point is 4.38 cm, and 76.6 cm at the contrast test point, which shows that straw mulch can prevent rainfall infiltration to a certain degree, increase surface run-off volume, and reduce soil water supply resource. The water potential of covering points at depths of 40cm to 200 cm is

generally higher than that of contrast test points, and equal at depths of 200-340 cm. The impact of straw mulch on the soil potential at depth is similar to water content, that is, weakens with increasing of depth. Besides, straw mulch make the relative stable ZEP (C) of January to April moved down 20-30 cm from the original 90 cm depth, which shows that straw mulch is profitable for soil water utilization in middle and shallow layers (0-120 cm).

3.4 Impact of straw mulch on evaporation

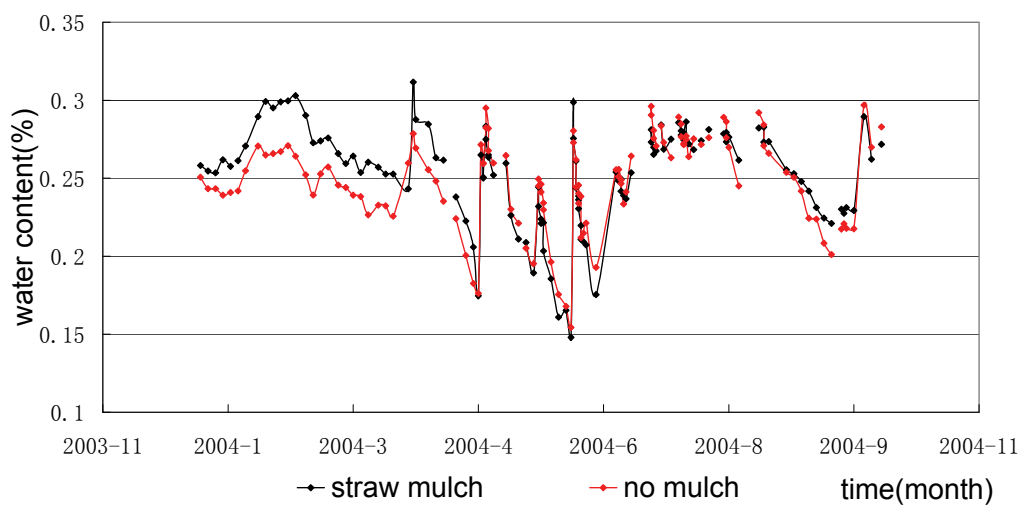


Fig .6 Contrast of soil water content at 20 cm depth

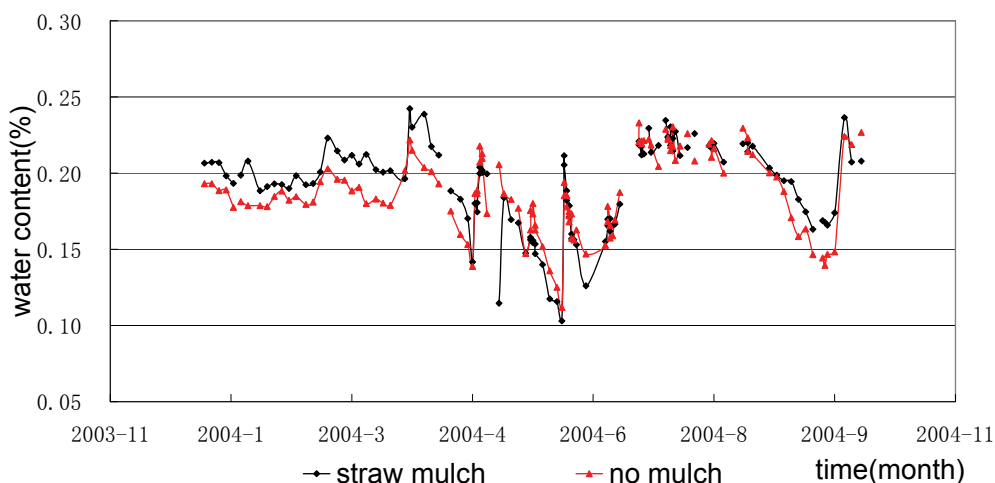


Fig7 Contrast of soil water contentat 30 cm depth

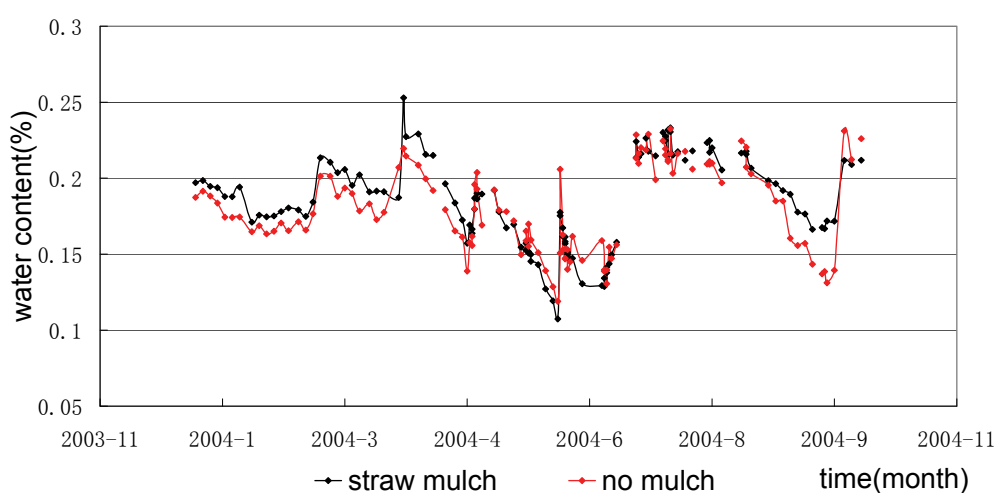


Fig .8 Contrast of soil water content at 40 cm depth

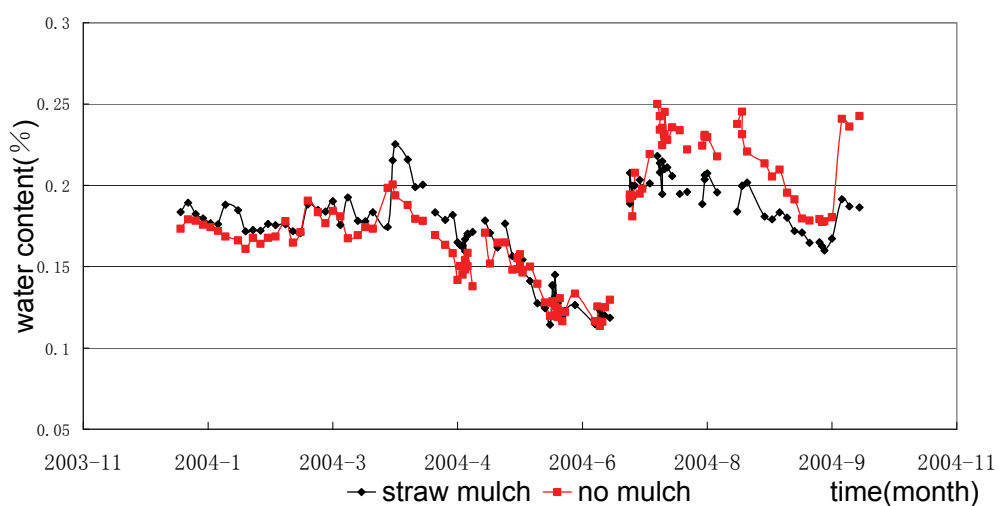


Fig .9 Contrast of soil water content at 60 cm depth

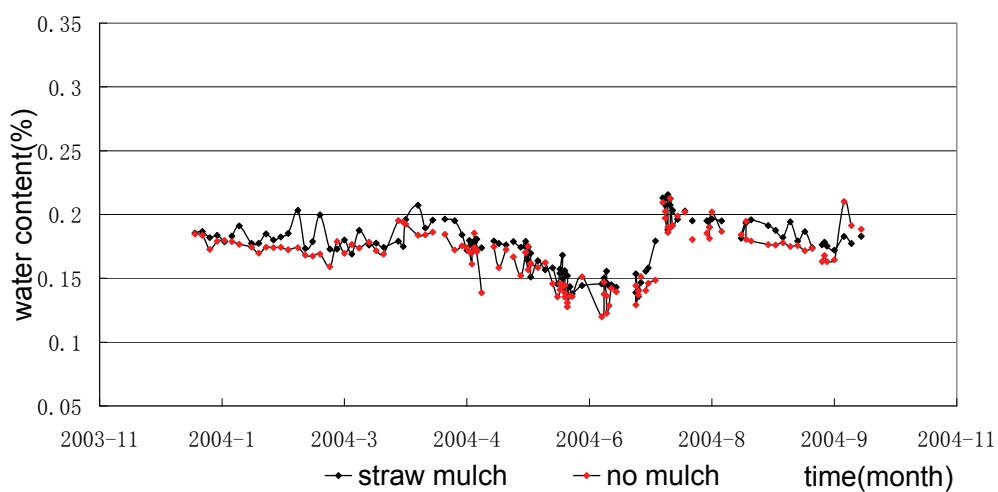


Fig .10 Contrast of soil water content at 100 cm depth

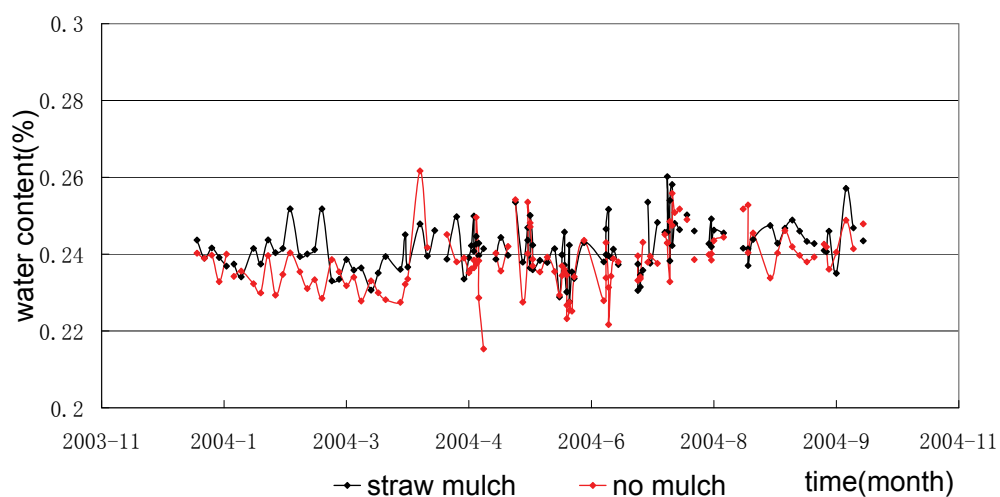


Fig. 11 Contrast of soil water content at 200 cm dept

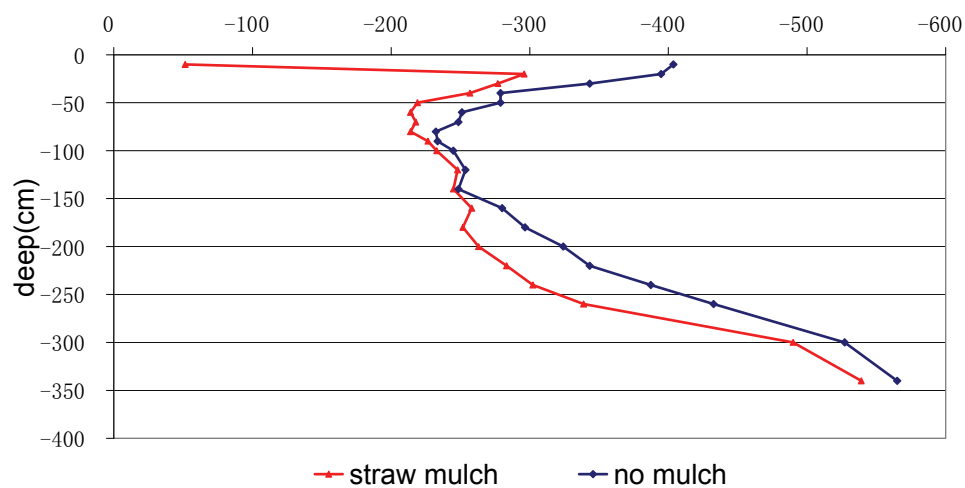


Fig.12 Contrast of total water potential of soil profile in drought period (2004.3.20)

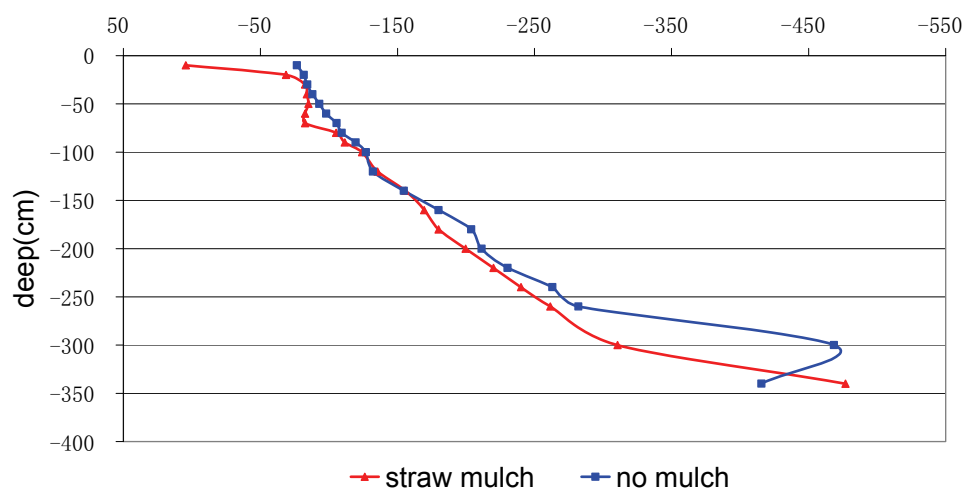


Fig .13 Contrast of total water potential of soil profile in high water period (2004.7.12)

The evaporation includes soil surface evaporation and crop transpiration, and is difficult to measure directly, especially over a long-term experiment. As to amount of soil surface evaporation, presently mostly adopt MLS, but the technology is not mature, therefore in need of further research and development. Analyzing crop evapotranspiration is comparatively complex, workload of direct measurement is big but not complex, which is unsuitable to monitoring of long-term test, at present it mainly use the very detailed meteorological information, adopts Penman formula recommended by FAO for counting. Along with development of numerical simulation, the simulation result also can reach the forecast demand by use of fully actual observation data. In view of actual conditions of test, this research adopted flux method to measure the evaporation capacity of soil, and predecessor of this research group has carried out a more in depth research on this method, showing that the precision of evaporation capacity of the soil is high by flux method, and error is as low as 3% (Jing Enchun et al. 1994).

Fig. 14 displays the annual surface transpiration results for 2004. The transpiration closely reflects the precipitation and dynamic volume of irrigation (i.e. increased precipitation results in increased transpiration). From January to March 2004, it was mainly evaporation, with temperature rebounding, the surface evaporation strengthens slowly. From mid April to mid October 2004, it was mainly the vegetation transpiration, with temperature rebounding, growth rate of crop accelerates, the transpiration enhances continuously, and the accumulated transpiration adds in straight line trend. The weaker transpiration period, which is also main seedling of crop and too small precipitation as well as no irrigation period, the transpiration of straw mulch point is obviously lower than that of contrast test point, it shows that this period, namely from January to April and again from October to December (2004), straw mulch can efficiently

prevent invalid loss of surface soil water. The comparatively stronger transpiration period, which is also relatively growth bloom period of crops and highly centralized precipitation, amount of irrigation period, the transpiration of straw mulch point is obviously higher than that of contrast test point, it shows that this period, namely from April to October 2004, straw mulch can enhance transpiration. The total transpiration capacities of test point 1 and 2 are 802.45 mm and 809.01 mm respectively, which are equivalent in total capacity. From these results, it is evident that when evaporation gives priority to surface evaporation, straw mulch can efficiently restrain the evaporation of soil water; when gives priority to vegetation transpiration, straw mulch can markedly accelerate vegetation transpiration.

3.5 Impact of straw mulch on infiltration capacity

Straw mulch gives more marked influence to infiltration capacity—at depths of 220 cm (Fig. 15). From mid January to early April (2004), the infiltration velocity of straw mulch point was lower than that of the contrast test point, that is, straw mulch is not conducive to infiltration of deep soil water. From early April to mid June (2004), the infiltration velocities of the two test points are equivalent, that is, there is no marked influence of straw mulch to infiltration of deep soil water. From early July to mid August (2004), the precipitation reached as high as 308 mm, accounting for over 60% of the annual precipitation. The infiltration velocity at the straw mulch point was higher than that of the contrast test point, which showed that under heavy precipitation events, straw mulch can efficiently accelerate deep infiltration. The accumulated infiltration capacity displayed from mid January to mid July (2004), the infiltration capacity of contrast test point was markedly higher than that of straw mulch point; from late July to late December (2004), the infiltration capacity of contrast test point was markedly lower than that of straw mulch point.

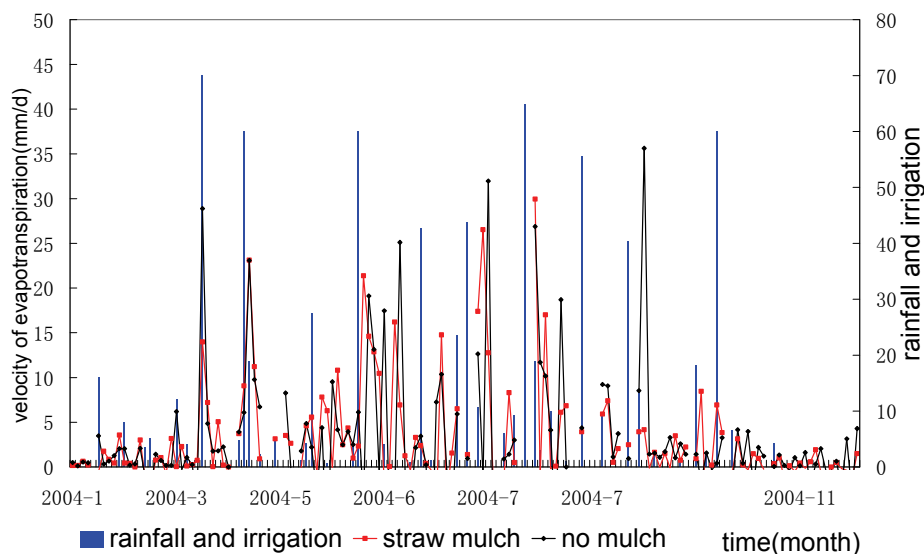


Fig.14 Comparison of transpiration velocity

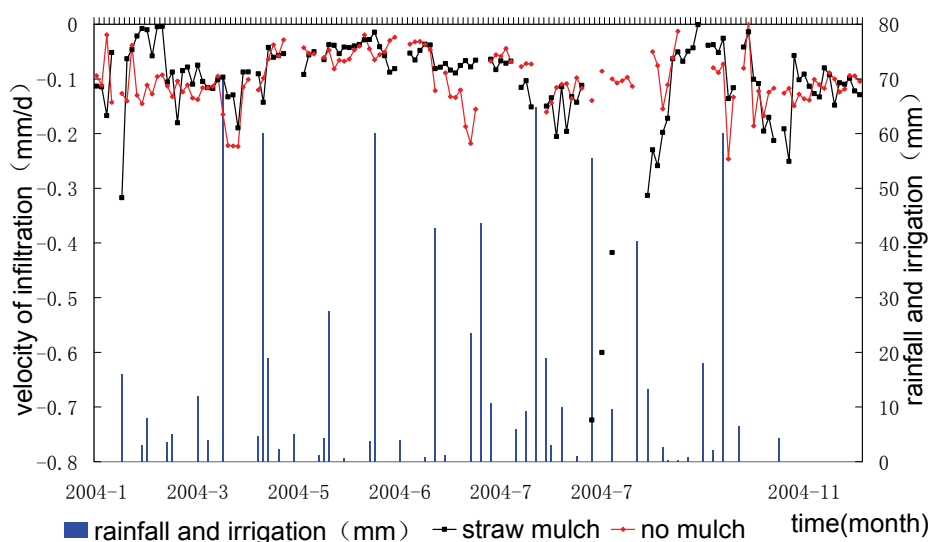


Fig.15 Comparison of infiltration velocity –at 220 cm depth

4. Conclusions

The volumetric water content of soil and the flow of water at the two test points have systematic error, and certain regularity. The systematic error of volumetric soil water content decreases along with its level falls and depth of soil profile increasing. At depths of 0-180 cm, a line negative relationship appeared between the volumetric water content of soil and time, with increasing depth, the slope of straight line trends to increase. But at depths of 0-40 cm, the difference of the two water contents fluctuates around the first irrigation before the beginning of spring of each year, and which weakens with increasing of depth. At depths of 200-340 cm, the water content of soil remains

stable year round, suggesting that the water content at these depths is not related to time.

Research shows that the effect of the straw mulch to soil water movement mainly relates to precipitation condition, climate terms, growth state of crops, soil depth and initial water content level of soil. The effect of mulch to the water content of soil is strongest at the shallower depths of in 0-180 cm, as opposed to the deeper soil depths of 180 cm-340 cm which are not affected by surface mulch conditions. During drought periods, the water content of the test point is higher than that of contrast point, and in high water periods, only at 10 cm depth, the water content of test point is

slightly higher, and water contents of other points are equivalent for the most part. The soil water potential data revealed that straw mulch is favorable for soil water utilization of mid and shallow soil layers (0-120 cm) during drought.

Straw mulch strongly influences surface evaporation and infiltration of soil water. When evaporation is dominated by surface evaporation, straw mulch can efficiently restrict the evaporation of soil water; when evaporation is dominated by vegetation transpiration, straw mulch can markedly accelerate vegetation transpiration. In drought periods, straw mulch is not conducive to infiltration of deep soil water, and the infiltration velocity is higher than that of the contrast point in high water period.

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