The Journal of Animal & Plant Sciences, 25 (3 Suppl. 1) 2015 Special Issue Page: 22-27
ISSN: 1018-7081

EFFECT OF FARMLAND SURFACE COVERED POROUS MULCH MATERIALS ON SOIL WATER, HEAT AND WATER USE EFFICIENCY OF MAIZE

L. S. Feng[1], Z. X. Sun[1*], C.R. Yan[2*], M. Z. Zheng[3], J. M. Zheng[1], N. Yang[1], W. Bai[1] and C. Feng[1]

[1]Liaoning Academy of Agricultural Sciences, Shenyang, Liaoning 110161, PR China;
[2]Chinese Academy of Agricultural Sciences, Beijing 100081, PR China;
[3]The University of Tennessee, Knoxville, 37996, USA.
*Corresponding author: sunzx67@163.com; yancr@ieda.org.cn

ABSTRACT

A surface covered with ordinary mulch increases runoff in the presence of precipitation, leading to limited application. However, using a porous membrane to cover surfaces can solve the problem of rainfall infiltration. In order to study the impact of using porous mulch to allow soil water heat to be utilized in a more efficient manner, we have carried out this study. We have found that porous mulch warms the surfaces and allows for water retention during the early stages of maize growth. During the middle and late stages of maize growth, the mulch cooled the surface. The moisture of the soil when covered by porous mulch was uniformly distributed during the dry season, when ordinary mulch would cause soil desiccation. Water utilization efficiency of crop that covered porous mulch respectively increased by 0.37kg/m^3, 0.45kg/m^3, 0.81kg/m^3 than that of covered the ordinary mulch, covered straw or the bare land in respectively.

Key words: Maize; Porous Mulch; Soil Moisture; Soil Temperature; Water Utilization Efficiency.

INTRODUCTION

Arid regions cover approximately 45% of the earth's land surface, allowing dryland farming systems to constitute the world's largest biome. This makes them indispensable for food production (Schimel, 2010). Field crop production is constrained by limited water resources (Rockstrom *et al*., 2007), especially when combined with lower soil temperatures during the seeding stage (Liu *et al*., 2009). Meanwhile, preservation of soil moisture by covered it is an effective method of increasing the efficiency of rainfall use and crop yields in arid and semi-aird regions (Yao *et al.*, 1998). Since its introduction in China in the 1960s, mulch has been widely used for preserving soil moisture, and now, China has the largest mulching industry in the world (Lan *et al.*, 2013). Studies have found that mulching could increase 30% of soil water storage capacity, reduce 50% of evapotranspiration, and decrease more than 15% of water deficit compared to bare ground cultivation (Zhang *et al.*, 2011). In particular, when the spring drought came, the preservation of soil moisture encouraged drought relief (Wang *et al.*, 2006). Studies have shown that mulching also affects the ability of precipitation to absorb into the soil, causing soil desiccation and higher crop temperatures in the late stages of growth. This also exacerbated the depletion of soil moisture and nutrients, leaving it susceptible to dehydration and production cuts, and preventing the sustainable production of next-stubble crops (Dang *et al.*, 2003). For mulching problems, the Shanxi Academy of Agricultural Sciences has developed porous mulch (Yao, 2000), and after ten years of improvement, has formed a relatively complete technology and preparation process. On this basis, our study investigates the impact of covered porous mulch material on the changes in soil water and heat in the maize field. We aim to provide a more technical reference for the large-scale application of this covered material.

MATERIALS AND METHODS

Test Materials: The experiment was conducted in the Chinese Ministry of Agriculture Fuxin Agricultural Environment and Farmland Conservation Scientific Observation Experiment Station in 2012 (North latitude 42.51°, 122.58°), and the experimental maize was TIEYAN 24. Our test used porous mulching material, a product with unidirectional water seepage characteristics. We examined this by adding a certain percentage of water seepage additives in the low-density polyethylene material during the manufacturing process. The pore size was between 5 to 10 microns, the seepage rate was greater than or equal to 12mm/ (cm^2 5cm 23°C h 101.3 kPa), and the water retention of covered the free surface was greater than or equal to 40% (100°C 30min 101.3 kPa). Ordinary mulch (Polyethylene film) and seepage mulch both had thicknesses of 0.08mm and widths of 1200mm. The meteorological indicators of the test area are shown in Table 1.

Experimental Design: The study used a randomized block design and set up four treatments including bare ground, covered ordinary mulch, covered porous mulch and covered straw. Each treatment was repeated three times, and the residential area was 48m^2. Eight rows of maize were planted in each residential area, with 50cm row spacing and 30cm plant spacing. Before sowing, the plowed land was prepared and 225 kg·ha^{-2} of the DAP (containing N18%，$P_2O_5$46%) and potassium sulfate (containing K_2O 46%) and urea (containing N 46%) 450 kg·ha^{-2} were applied. Sowing took place on April 29, and the soil was then covered with mulch or straw.

Soil temperature Survey Method: From the seedlings, we used an HC-06 miniature temperature logger to monitor the geothermal temperature at 10-20cm from the surface of each treatment per hour.

Survey Method of Soil water content: A soil auger was used to dry the sample in order to measure the moisture down to 100c from the surface every 15d. 10cm was measured for each layer, averaging three iterations. We measured one again after the rainfall.

Survey Method of Soil water consumption: Mulching materials and techniques significantly affect the microclimate around the crop canopy by changing the radiation budget of the topsoil, soil water transformation, aerodynamic properties, and soil temperature. These changes influence the crop yield, evapotranspiration, and the efficiency of water use (WUE) (Yang, *et al*.,2015a). Under the condition of the special environment，most of the models for estimating farmland evaporation are required to validate the application (Valipour *et al*.,2014). Many models could not estimate plastic mulching under the condition of soil evaporation. One of these was AquaCrop, a mode recommended by the Food and Agriculture Organization and still cannot be achieved from a simulation of the moisture changes in the process of plastic film mulching (Yang, *et al*., 2015b; Valipour, 2012; Valipour, 2015). While this adopts the porous membrane, we are still unable to accurately estimate the evaporation of soil moisture. Using the soil water balance method to calculate in this study, we obtain the equation as:

$$ETa = I + P - RO - DP + CR \pm \Delta SF \pm \Delta SW \quad (1)$$

In equation(1), *I* and *P* respectively represent irrigation and rainfall (mm) of that period, *RO* is the soil surface runoff (mm) for rainfall or irrigation, *DP* is deep soil percolation (mm), *CR* is groundwater rising from capillary to the root zone (mm) (due to lower groundwater levels, so ignore it),*ÄSF* is the lateral leakage of soil (mm), including the lateral inflow SF_{in} and lateral outflow SF_{out} (ignored in this test), and *ÄSW* is soil moisture variation (mm).

Water Utilization Efficiency: Water utilization efficiency (*WUE*) refers to the production of crop yields in the unit volume of water (including irrigation water and effective rainfall). It can be found using the following equation:

$$WUE(kg/m^3) = Y(kg/hm^2)/ET_a(mm) = 0.1 \times Y/ET_a(kg/m^3) \quad (2)$$

In Equation (2), *WUE* is water utilization efficiency, *Y* is crop yield per unit area (kg·ha^{-2}), and *ETá* is cropland actual evapotranspiration.

Table 1. Test area meteorological index data

Date	15/4-30/4	1/5-31/5	1/6-30/6	1/7-31/7	1/8-31/8	1/9-28/9	15/4-28/9
Precipitation(mm)	20.40	30.20	51.60	144.40	32.80	7.40	286.80
Atmospheric temperature(°C)	11.06	18.70	20.49	23.19	23.06	17.57	—
Active accumulated temperature(°C)	165.9	579.7	614.8	718.9	714.9	491.9	3286.10
Dew point temperature(°C)	0.53	5.78	12.43	18.03	16.21	8.02	—
Sunshine duration(h)	106.33	341.08	297.7	307.4	296.4	226	1574.91
Wind speed(m·s^{-1})	3.07	3.04	2.28	1.92	1.67	2.34	—
Solar radiation(MJ·m^{-2})	44.73	139.84	111.05	92.22	106.68	104.31	598.83
ET_0(mm·d^{-1})	2.98	5.33	3.69	2.97	3.44	3.73	—

RESULTS AND ANALYSIS

The impact of covered porous mulch material on soil temperature: Throughout the growth period of maize, the soil temperature variation of the covered porous mulch and other the covered materials is shown in Fig. 1. As can be seen, the soil temperature of the bare ground and the straw were low, and the trend was more consistent, but the straw-covered ground temperature was lower; The soil temperature change of the covered porous mulch was consistent with that of the covered ordinary mulch. The upper and lower soil temperature change of the covered porous mulch was more uniform, but soil temperature of the covered ordinary mulch at 20cm was higher than that at 10cm. After calculation, throughout the growing period of maize, the average soil temperatures of the covered porous mulch, the covered ordinary mulch, the covered straw, and the bare land from 0 to 20cm were respectively 21.29°C, 22.84 °C, 18.70 °C, and 20.20 °C.

The impact of covered porous mulch material on soil moisture: Changes in soil moisture of covered porous mulch and other material are shown in Fig.2. On the whole, the soil moisture content of the covered porous mulch and the straw was higher than that of the covered ordinary mulch, and the bare land planting soil had the minimal moisture content. After sowing within 60 days, the soil moisture content of different treatments presented a trend that reflected lower moisture at higher soil levels and higher moisture at lower levels. The soil moisture content of the porous mulch and the straw was higher than that of the ordinary mulch. Bare ground planting had the least moisture content. After sowing for 70 to 100 days, in the rainy season, more moisture was found in the higher levels of soil, where the moisture of the seepage mulch from 0 to 60cm was higher than other treatments. After sowing for over 100 days, during the region's dry season, the ordinary mulch presented a soil drought phenomenon in the deep soil. Bare ground and straw presented a drought in the upper soil, but the soil moisture of the porous mulch was more evenly distributed.

The impact of covered porous mulch material on the utilization efficiency of crop water: The water consumption, yield and, water utilization efficiency of the different mulching treatments for maize are shown in Table 2. The farmland used to test the seepage mulch showed the least amount of water consumption, with decreases of 26.7mm and 33.9mm for the ordinary mulch and 67.3 and 74.5mm for the bare ground. Because the relatively low pre-ground temperature of the straw affected the crop growth, the production was not high. However, due to the temperature and good moisture conditions of the porous mulch, the production increased significantly by 6.64%, 19.72% and 16.76% when the ordinary mulc, the straw, and the bare ground, respectively. Water utilization efficiency of covered porous seepage mulch was respectively increased by 6.64%, 19.72% and 16.76%.

Table 2. Yield and water use efficiency of maize in different mulching materials treatments.

Treatments	Water consumption (mm)	Yield (kg・ha^{-2})	Water use efficiency (kg・m^{-3})
Covering porous mulch	388.5 cC	11750.2aA	3.02 aA
Covering ordinary mulch	415.2bB	11018.6bAB	2.65 bB
Covering straw	381.3cC	9815.1cB	2.57 bcBC
Bare ground	455.8aA	10063.7cB	2.21 cC

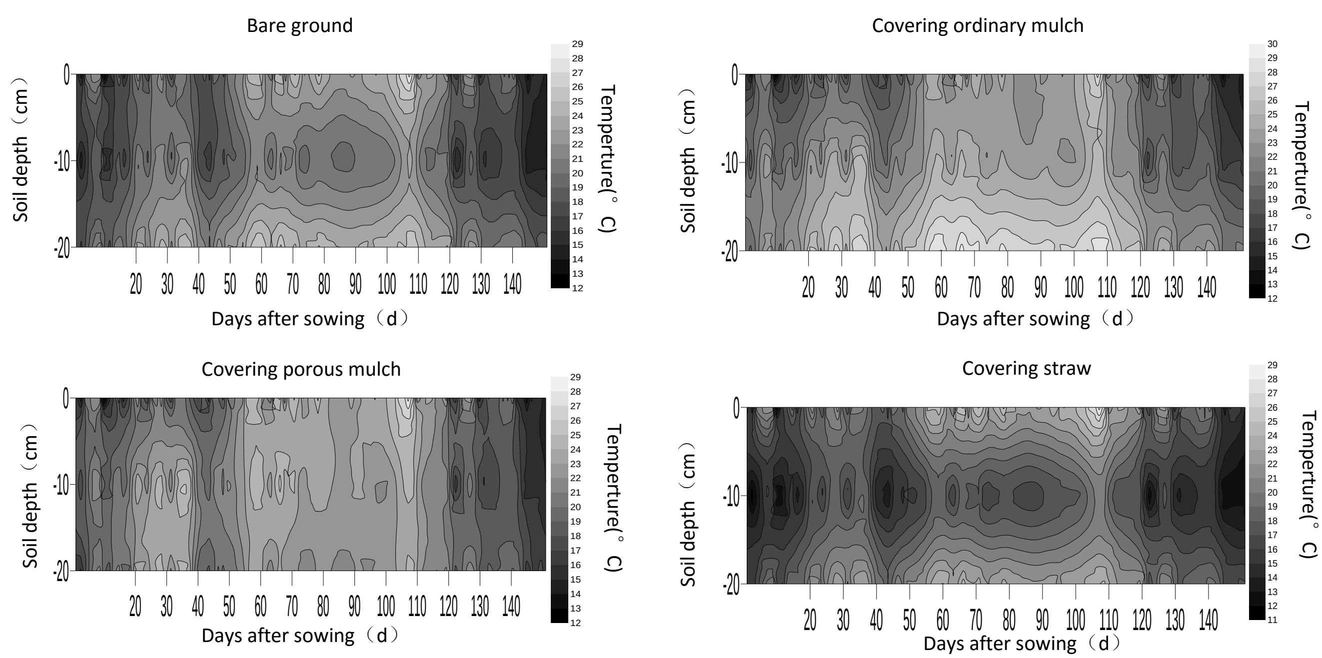

Figure 1. Effect on soil temperature of covering porous mulch and others materials

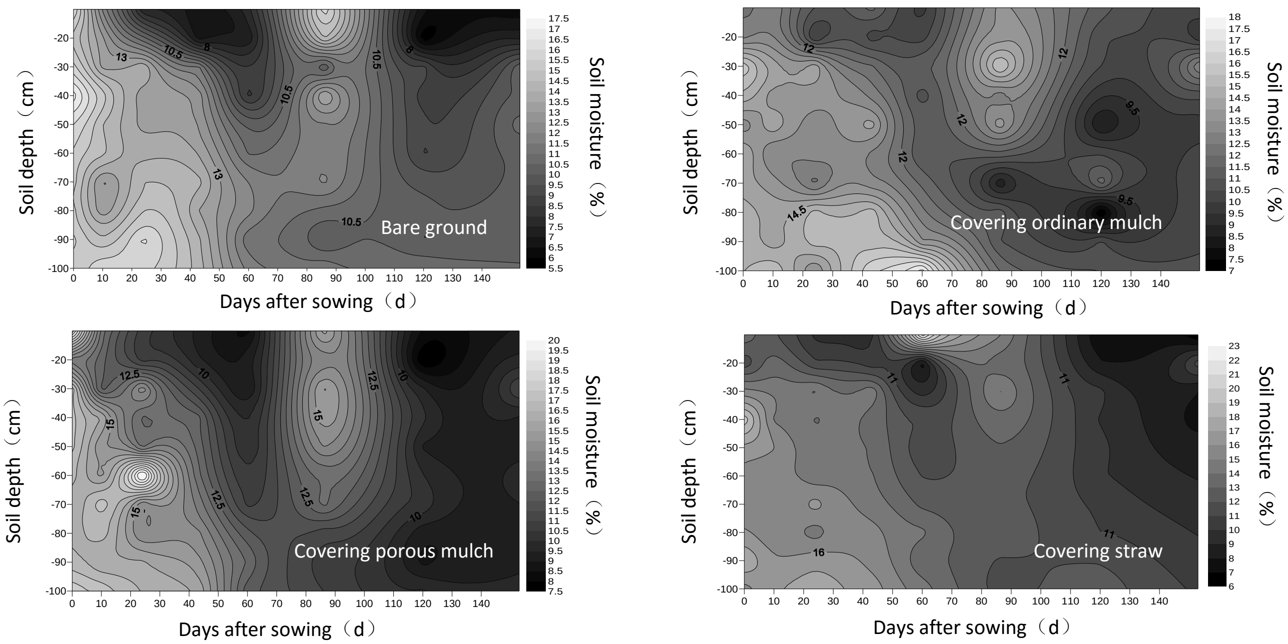

Figure 2. Effect on soil temperature of covering porous mulch and others materials

DISCUSSION

There is little precipitation in arid and semi-arid regions, especially during the dry season. Precipitation is less than 10mm, too little to be used by crops (Yao, 2000). In the case of the porous mulch, water passes into the soil under the membrane due to gravity (Yao, 2000; Yin, *et al.*, 2000; Li *et al*., 2007). Because the passage area and the non-passage area ratio are small, it is unlikely that water will reenter the atmosphere from beneath the porous (Yao, 2000). The speed of distribution is low, so there is a clear imbalance of water infiltration and water loss (Yao, 2000; Cui *et al.*, 2008). Meanwhile, the main raw material of porous mulch is polyethylene plastic, which is very elastic (Yao, 2000; Xu *et al.*, 2007). When the narrow passage is affected by water gravity, the passage becomes large, allowing water from the surface to smoothly infiltrate the soil below (Yin, *et al.*, 2000). When the infiltration of membrane surface rainwater is complete, the narrow water passage is closed by the force of the membrane, preventing water evaporation (Yao, 2000). Since the recoverability characteristics of the elastic force give the porous mulch the unidirectional seepage self-adjusting capabilities, the soil moisture content is higher when the porous mulch is in place (Li *et al.*, 2007; Cui *et al.*, 2008).

Xu *et al*. (2010) studied the effects of porous mulch, ordinary mulch, straw, and bare ground on maize growth. They found that with porous mulch, the maize plant water content, the leaf chlorophyll content, the photosynthetic rate, and the maize yield are significantly higher than others. Dry matter accumulated faster than others, but the authors of the study did not specify the reasons for this. Cao *et al*. (2013) showed that the porous membrane inhibits the soil moisture evaporation, reduces water consumption, and increases the water use efficiency of maize. However, their findings are not systematic research on the distribution of soil water and heat during the growth period of maize. So, the effects of porous mulch on soil moisture and heat distribution have not been completely studied in depth (Xie *et al*.,2014).

Conclusion: In this study, throughout the growth period of maize, the average soil temperatures of that covered by porous mulch decreased by 1.55 °C when compared with ordinary mulch, and increased by 1.09 °C and 2.59 °C when compared with bare land and straw. The main reason was that the pore size of porous mulch shrinks when the soil temperature is low in the early growth stage. This leads to a reduction of soil heat loss. When the soil temperature is too high in the medium growth stage, high pressure will build up under the membrane, and the pore size increases, which is conducive to heat dissipation. There is a gas exchange inside and outside, and a more uniform distribution of soil moisture occurs, unlike the ordinary mulch, which causes soil desiccation (Yao, 2000). Because porous mulch creates better conditions for the growth and development of a crop, yield and water utilization efficiency were significantly improved. Out study showed that in the early growth stage of Maize, using porous mulch played a better role in the warming and water conservation Similar to the ordinary mulch, and in the middle and late growth stages, using porous mulch played a better role in cooling and water conservation similar to covered straw. Porous mulch also makes better use of disposable precipitation, which is less than 10mm, allowing it to preserve soil moisture in arid and semi-arid regions. The ordinary mulch such as the technology of whole field surface plastic mulching obtained a widespread application in the annual rainfall less than 300 mm of northwest China, because it is very lower farmland surface evaporation(Jin *et al*., 2010). However, it increases the surface runoff when there is more precipitation, so the technique is not popularized, and consequently, is not applied in more areas with 400-600mm of annual rainfall. Using a porous membrane can effectively solve the problem of rainfall infiltration, potentially giving this technology a wider range of applications.

Acknowledgements: The study was conducted under the support of the National Science and Technology Support Project of China (NO.2012BAD09B01), the Project of Liaoning BaiQianWan Talents Program (2013921058), the Special Fund for Agro-scientific Research in the Public Interest (201503105), the Cultivation Plan for Youth Agricultural Science and Technology Innovative Talents of Liaoning Province (2014017).

REFERENCES

Cao J.J., Y.Z. Liu, W.X. Li, K.P. Jin, Y.Y. Du, H.L. Wang and W.Y. Zhao (2013). Effect of different mulching treatments on soil water content and temperature and water use efficiency of maize. Chinese Agricultural Science Bulletin, 29(33): 107-111.

Cui F.Z., X.Q. Guo, J.P. Hao, T.Q. Du and X.B. Yan (2008): Study on soil temperature variation of water-permeability plastic film mulching on dry land foxtail millet. J. Shanxi Agric Univ., 28,(2), 172-175.

Dang T. H., M.D. Hao, S.L. Guo and G.X. Cai (2003). Effect of plastic-film mulch on water and nitrogen use by spring maize and on fate of applied nitrogen in the southern loess plateau. Chinese J. Applied Ecology, 14, (11),1901~1905.

Jin S.L., L.M. Zhou, F.M. Li and G.Q. Zhang (2010): Effect of double ridges mulched with wide plastic film on soil water, soil temperature and yield of corn in semiarid Loess Plateau of China. Agricultural Research in the Arid Areas, 28(2):28-33.

Lan Y.C., L.X. Shen and R.F. Li (2013): Effects of different film mulching on soil temperature and moisture. Chinese Agricultural Science Bulletin, 29,(12),120-126.

Li N.N., J.P. Hao, J.Z. Yang and X.B. Yan (2007): Effects of water-permeability plastic film mulching on physiological characteristics of sorghum in drought land. J. Shanxi Agric Univ., 27,(2),146-148.

Liu, C.A., S.L. Jin, L.M. Zhou, Y. Jia, F.M. Li, Y.C. Xiong and X.G. Li (2009). Effects of plastic film mulch and tillage on maize productivity and soil parameters. European J. Agronomy, 31, 241–249.

Rockstrom, J., M. Lannerstad and M. Falkenmark, (2007): Assessing the water challenge of a new green revolution in developing countries. Proceedings of the National Academy of Science of the United States of America, 104, 6253–6260.

Schimel, D.S (2010). Drylands in the earth system. Science, 327, 418–419.

Valipour, M. (2012). Ability of box-Jenkins models to estimate of reference potential evapotranspiration (A case study: Mehrabad synoptic station, Tehran, Iran). IOSR J. Agriculture and Veterinary Science (IOSR-JAVS), 1(5), 1-11.

Valipour, M. (2012). Hydro-module determination for vanaei village in Eslam Abad Gharb, Iran. ARPN J Agr Biol Sci, 7(12), 968-976.

Valipour, M. (2014). Analysis of potential evapotranspiration using limited weather data. Applied Water Science, 1-11.

Valipour, M. (2015). Importance of solar radiation, temperature, relative humidity, and wind speed for calculation of reference evapotranspiration. Archives of Agronomy and Soil Science, 61(2), 239-255.

Wang Q., Ma, J.P. Guo, L. Liu and Z.S. Sheng (2006): Example study on soil water and thermal effect of corn plastic mulching. Chinese J. Agrometeorology, 27,(3),249-251.

Xie W.Y., H.P. Zhou, Z.X. Yang and C.L. Guan (2014): Effect of different mulching patterns on soil moisture and crop producticity of spring maize. J. Soil and water consercation, 28(4):128-132.

Xu L., W. An and J.M. Hao (2007). Effect of water-osmosis plastic membrane on maize growth. J. Maize sciences, 15, (4):119-122.

Xu L., An Wei and J.P. Hao (2010). The effect of water-osmosis plastic membrane on physiology, yield component and yield for drought maize, J. Arid Land Resources and Environment, 24(8):180-185.

Yang N., Z.X. Sun, L.S. Feng, M. Zheng Zi., D.C. Chi, W.Z. Meng, Z.Y. Hou, W. Bai and K.Y. Li (2015a): Plastic Film Mulching for Water-Efficient Agricultural Applications and Degradable Films Materials Development Research. Materials and Manufacturing Processes, 2015, 30(2), 143－154.

Yang N., Z.X. Sun, L.Z. Zhang, J.M. Zheng, L.S. Feng, K.Y. Li, Z. Zhang and C. Feng (2015b). Simulation of water use process by film mulched cultivated maize based on improved AquaCrop model and its verification. Transactions of the Chinese Society of Agricultural Engineering,31:,122-132

Yao J.M. (2000). The Invention and Application of Water-permeability Plastic Membrane. Acta Agronomica Sinica, 26,(2) :185-189.

Yao J.M., B.L. Zhang and H.S. Yin (1998): Rainfall validated by water-osmosis membrane in semi-arid land. Bulletin of soil and water consercation, 18,(3),24-29.

Yin H.S., J.M. Yao and R.P. Yang (2000). Study on rainfall utilization technique by water-permeability plastic film covering. Research of soil and water conservation, 7,(4), 47-49.

Zhang S.F., S.X. Chai, Y.C. Lin, L. Chang and C.G. Yang (2011). Effects of plastic film mulching patterns on soil moisture and spring wheat yields in drought years. Chinese J. Agrometeorology, 32,(3) ,368 -374.