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Field investigation on effects of wheat-straw/corn-stalk mulch on ecological environment of upland crop farmland*

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Abstract: This work systematically investigates the effects of wheat-straw/corn-stalk mulch on the ecological environment in upland crops (winter wheat, summer corn) field from 1997 to 1998. With and without mulch soil moisture distribution, water demand, day and night variation of soil temperature, weeds control, crop yields, water and soil conservation, as well as improvement of soil texture were experimentally investigated. The optimal mulch rate for both water saving and yield-increase was determined. Ineffective interplant evaporation can be turned into effective transpiration of leaf by application of wheat-straw/corn-stalk mulch, which enhances the utility factor of soil moisture and reduces irrigation norm, and may also regulate soil temperature, increase soil fertility, and improve soil texture after being returned to the field. Wheat-straw/corn-stalk mulch inhibits evaporation of moisture so that accumulation of salinity near the soil surface is prevented, and thus ameliorates salinization of land. In the region of severe soil erosion, mulch is used to cover land so as to forestall hydraulic and wind erosion of the soil.

Key words: Wheat-straw/Corn-stalk mulch, Upland crop, Mulch rate, Soil moisture, Soil temperature, Crop yields, Weeds control, Water-saving role

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INTRODUCTION

The status of water resources shortage is increasingly acute in arid and semi-arid areas of northern China. Water saving becomes one of the key problems in agricultural production. Agricultural water saving measures have to be taken, so as to fully tap the latent power of water resources, and enhance the crop to water utility factor. Water shortage is common all over the county.

As the residue after crop harvest, wheat-straw/corn-stalk will be a severe environmental problem, if it is not well disposed of. It was often reported that wheat-straw/corn-stalk burning by farmers near airports produces huge amount of smoke in the sky over airports and decreases visibility, thus endangering plane landings. Rational use of wheat-straw/corn-stalk for mulching farmland as shown in Fig.1 can play a water saving role.

Use of wheat-straw/corn-stalk to mulch soil is both an ancient and a novel agricultural technique. Long ago, hillside fields were mulched with crop residue for water and soil conservation purposes. In recent years, in view of the water resources shortage, and the advantages of popularizing the use of local material and wheat-straw/corn-stalk mulch, it is increasingly and extensively paid attention to. Although wheat-straw/corn-stalk mulch application has a long history, the mulch techniques have not been well understood as yet, and the mechanism of water saving and conservation, and crop yield increase due to the mulch have not yet been clarified. Limits in experimental condition, mulch application studies are still simple comparisons of crop yield from soil with mulch and without mulch. In fact, mulch rate has important effects on water conservation and yield increase. Mulch in insufficient amount

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cannot help much in conserving soil moisture. Excessive amount of mulch will greatly lower soil temperature, hinders soil ventilation and thus crop growth, though it helps water conservation.

Fig.1 Wheat-straw/corn-stalk mulch in the field

Many researchers conducted experimental study and numerical simulation of water and temperature distributions in bare soil (Horton et al., 1984; Milly et al., 1982; Penman et al., 1957; Van et al., 1957; Sophcleous, 1979). For the case of wheat-straw/corn-stalk, however, only a few researchers (Bristow et al., 1986; Dong, 1998) have made the studies. Especially the study of effects of wheat-straw/corn-stalk on the ecological environment in upland crop farmland is rare. Field investigation of wheat-straw/corn-stalk mulch is helpful to find out physical mechanisms of water conservation and yield increase. Also, it provides verification data for a mathematical model. This paper can significantly popularize the use of wheat-straw/corn-stalk mulch techniques in semiarid and arid areas.

EXPERIMENTAL ARRANGEMENT AND METHODOLOGY

Experimental details

The experimental district located in Henan Province's Xinxiang County, which is in semi-arid climate area, has 600 mm mean annual precipitation, varying much in amount and distribution over the year. Soil texture in the experimental field could be roughly divided into three layers: 0 – 30 cm sandy loam, 30 – 75 cm clay and 75 – 100 cm silty sand. Summer corn was dibbled before harvesting winter wheat. Planting density was 50 × 25 (row spacing × spacing in the row). The experimental field consisted of 99-border checks, with each area being $3.3 \times 3.0\ m^2$. Under the condition of the same irrigation norm and fertilizer, the experimental arrangement involved mulch rate and irrigating frequency. Two repeats were set for each arrangement. To avoid interaction of various arrangements or repeats, a protection zone was set up around the area of each arrangement or duplicated arrangement plot. The mulch application was started at the seedling stage, and an exactly weighed amount of mulch was applied each border check, was uniformly placed on the field surface.

Water source in experimental field was

underground water. Well and underground pipes irrigation system is used. The irrigation flow rate was controlled at 600 m^3/ha.

Observing method

Soil moisture was determined by the classical drill-oven method. Soil depths for summer corn were 0 – 10 cm, 10 – 20 cm, 20 – 30 cm, 30 – 40 cm and 40 – 50 cm, respectively, and for winter wheat were 0 – 10 cm, 10 – 20 cm, 20 – 30 cm, 30 – 50 cm, 50 – 70 cm and 70 – 100 cm, respectively. Underground soil temperature was measured with a Γ-shaped thermometer at depth of 5 cm, 10 cm, 15 cm, and 20 cm, respectively. Temperature of the mulch layers upper side and under side and of the bare soil surface was measured by ordinary mercury thermometer. Soil moisture was usually observed weekly; additional measurements were made after and before rainfall or irrigation. Observing time for soil temperature was 5:00 AM and 2:30 PM.

EFFECT OF WHEAT-STRAW / CORN-STALK MULCH ON SOIL WATER

Soil moisture distribution in summer cornfield mulched by wheat-straw

We systematically investigated the influence of wheat-straw mulch rate on soil moisture distribution in a summer cornfield. Typical soil moisture distribution with and without mulch was as shown in Fig.2. Data in Fig.2 were taken on August 2, 1997 during heading stage when mulch was applied at rate of 5.25 t/ha. It follows from the figure that soil moisture when mulch was used was considerably greater than that when mulch was not used in the cultivation layer. Soil moisture distribution during the growth stages of corn is shown in Table 1 showing that moisture of soil with mulch was always greater than that for the bare soil at each growth stage; and soil moisture increased with mulch rate. Our successive measurements revealed that soil moisture is a function of space and time.

Water consumption for upland crop consists of interplant evaporation and transpiration of leaf. Preventing ineffective soil evaporation is one of the main means to improve

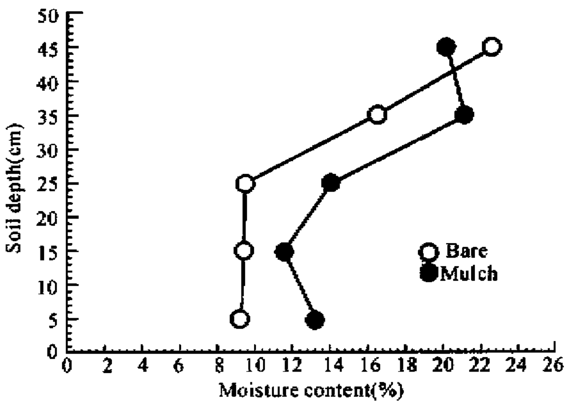

Fig. 2 Comparison of soil moisture with and without mulch

Table 1 Comparison of soil moisture distributions with and without mulch in cornfield

Growth stage	Mulch rate (t/ha)	Soil depth (cm)				
		0 – 10	10 – 20	20 – 30	30 – 40	40 – 50
Seedling stage	0	9.92	14.94	15.50	18.89	24.15
	5.25	17.53	16.83	22.21	27.39	25.81
Jointing stage	0	3.37	5.59	9.21	15.85	20.68
	5.25	5.86	7.11	15.41	18.83	22.87
Flowering stage	0	8.60	9.63	9.92	11.75	14.92
	5.25	9.18	10.01	11.61	18.63	19.42
Milk stage	0	8.43	10.40	11.24	14.02	16.52
	5.25	10.88	12.15	19.99	23.05	19.64

water status in the field. The mulch layer on the field surface can weaken the intensity of turbulent exchange between the atmosphere and soil water, so that soil moisture is prevented from evaporating, and thus, reduce ineffective water consumption. Ineffective evaporation from interplant can be turned into effective transpiration of leaf, thus raising the utility factor of soil water.

Results of water conservation due to mulch become intangible when a crop exhibits certain canopy. For corn, the mulch effect mainly concentrates on the seedling and jointing stages, and for wheat, on the jointing stage. In addition, the mulch effect is limited in, for example, the turn green stage of winter wheat. During this stage, the mulch would cause wheat seedlings to turn yellow, and soil temperature too lower to grow fine to wheat.

Water demand of winter wheat with and without mulch

Corn stalk was cut into 10 cm or so length and used as mulch. Variations of moisture within the 1.0 m soil layer with different mulch rate were observed in a wheat field. Comparison of the water demand of winter wheat with and without mulch is shown in Table 2. It follows from Table 2 that the water demand of winter wheat grown in soil with mulch reduces considerably, thus conserving 69.4 mm more water over that in the case of soil without mulch, and approximately saves an irrigation norm.

Table 2 Water demand for winter wheat with and without mulch

Growth stage	Duration (1997 – 1998)	Days	Stage water demand(mm)		Mean daily water demand (mm)	
			bare	mulch	bare	mulch
Seeding – Tillering	Oct.10 – Nov.7	28	40.8	35.2	1.46	1.26
Tillering – Overwinter	Nov.8 – Dec.25	47	57.2	47.8	1.22	1.00
Overwinter – Turngreen	Dec.26 – Feb.20	56	27.9	21.8	0.50	0.39
Turngreen – Jointing	Feb.21 – Mar.20	30	80.9	71.4	2.70	2.38
Jointing – Earing	Mar.21 – Apr.10	20	98.0	75.2	4.90	3.76
Earing – Milk	Apr.11 – May 3	22	128.6	120.5	5.85	5.48
Milk – Maturity	May 4 – Jun.3	31	133.7	125.6	4.31	4.05
Whole stage	Oct.10 – Jun.6	234	566.9	497.5	2.42	2.19

Crop coefficient

The potential evapotranspiration can be estimated by the well-known Penman(1948) formula below.

$$LE_{\mathrm{pt}} = \left[\frac{\Delta}{\gamma}(R_n - G) + LE_{\mathrm{a}}\right] \Big/ \left(\frac{\Delta}{\gamma} + 1\right) \quad (1)$$

where L denotes the latent heat of evaporation, G thermal flux of soil determined by soil temperature data, Δ slope of e-T curve at $T = T_{\mathrm{a}}$ (T_{a} is air temperature), γ constant of wet and dry bulb hygrometer equation, R_n net solar radiation, that is

$$R_n = (1 - \alpha) R_{\mathrm{S}} - R_{\mathrm{L}} \quad (2)$$

in which α is albedo and equals 15% ~ 25% for crop; R_{S}, R_{L} denote short wave and long wave radiation, respectively. R_{S} can be expressed as

$$R_{\mathrm{S}} = R_{\mathrm{A}}\left(a + b\frac{n}{N}\right) \quad (3)$$

where R_{A} is the possible solar radiation in clear sky, dependent upon latitude and month, n/N is sunshine percent, also determined by latitude and month, empirical constant, $a = 0.18$, $b = 0.55$ in temperate zone. R_{L} can be estimated by the FAO suggested formula,

$$R_{\mathrm{L}} = \sigma T_{\mathrm{a}}^4 (0.56 - 0.079\sqrt{e_{\mathrm{d}}})\left(0.1 + 0.9\frac{n}{N}\right) \quad (4)$$

where σ is Stefan-Boltzman constant, T_a in Kelvin degrees, e_d actual vapor pressure (hP_a), E_a value of E obtained by putting e_a instead of e_s in expression. FAO suggests

$$E_a = 0.26(e_{S2} - e_2)(1 + Cu_2) \quad (5)$$

Where e_{S2}, e_2 and u_2 denote saturated vapor pressure, local vapor pressure and wind velocity at 2m, respectively. C is function of air temperature, $C = C(T_{min}, T_{max} - T_{min})$, T_{max}, T_{min} are the maximum and minimum air temperature, respectively.

Now let E_t be water demand of crop, so crop coefficient K_C can be written as

$$K_C = E_t / E_{pt} \quad (6)$$

Crop coefficient curves of winter wheat are shown in Fig.3, where the abscissa indicates ten-day periods after planting. It follows from Fig. 3 that variation of crop coefficient exhibits waveform curve, with crest at about 200 days and trough at about 100 days after planting; and that during the whole growth stage of winter wheat, the crop coefficient for soil mulch is less than that for soil without mulch.

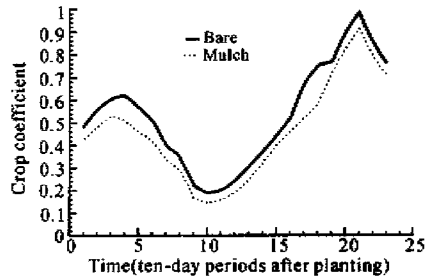

Fig.3 Mean crop coefficient curve of winter wheat

DAY AND NIGHT VARIATION OF SOIL TEMPERATURE

The day and night variation of soil temperature in soil with and without mulch in a summer cornfield is shown in Fig.4 (a, b, c, d), respectively. Fig.4a compares temperature on the wheat-straw mulch layer's upper side and under side; Fig.4b bare soil surface and mulch layer underside; Fig.4c and Fig.4d

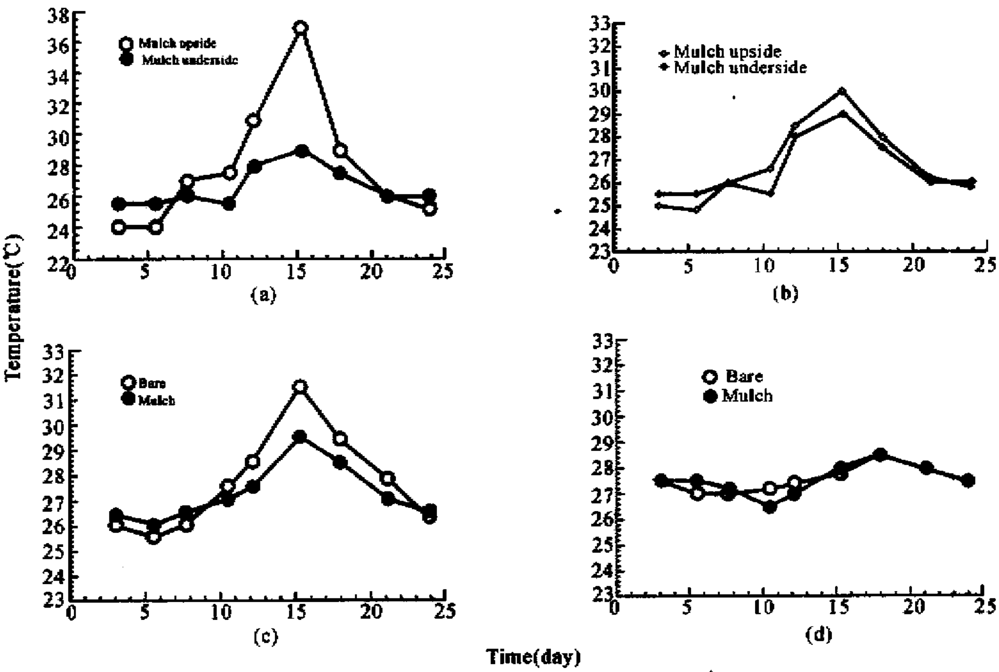

Fig.4 Comparison(a – d) of day and night variation of temperature in soil with and without mulch (during flowering stage, 5.25 t/ha mulch rate)

(a) upper side and under side of mulch; (b) bare soil surface and mulch underside; (c) 5 depth; (d) 20 depth show temperature at 5 and 20 cm depth of soil with and without mulch, respectively. Fig.4 shows that soil temperature after application of mulch decreases in the day, and is conserved in the night. Daily temperature variations of soil with and without mulch present waveform curves, with amplitude decreasing with increase in depth, and phase delays increasing with depth. The amplitude of temperature in soil with mulch is less than that in soil without mulch; and flattens with increase in depth. The decrease range in temperature for the mulch layer upper side and underside (Fig.4a) maximized, then with increase in depth, gradually reduces. Temperatures in soil with and without mulch nearly overlap at 20 depth; and the temperature curves tend to flatten. It is known that water interacts with heat in soil; and that the change in temperature certainly leads to capillary tension and variation of water viscosity, all of which affect crop growth.

WEEDS CONTROL

The consumption of water, fertilizers, absorption of heat and occupation of space by weeds in the field hamper crop growth. Investigation during the heading stage of corn revealed the role of wheat-straw mulch in controlling weeds. Table 3's results show that the more the mulch rate was, the more obvious was the role of mulch in controlling weeds. Mulch rate exceeding 5.25 t/ha almost decimated weeds in the field. With the role of mulch in controlling weeds, the ability to hold water and fertilizer would be promoted and non-point pollution from the use of chemical weed-killers can be prevented.

Table 3 The role of mulch rate in controlling weeds

Mulch rate (5.25 t/ha)	Weed numbers per border	Decrease percent(%)
0	1640	-
3.0	1120	31.7
5.25	172	89.5
7.5	85	94.8
12.0	48	97.1

INFLUENCES OF MULCH ON CROP YIELDS

Wheat-straw/corn-stalk mulch's alteration of the ecological environment in the field can affect crop growth. Results of water conservation due to mulch can alleviate water stress, and promote roots growth. According to our field investigations, roots grow well in soil with mulch. The mulch increased considerably the ear length, thousand-grain weight and yield of crop.

It should be noted that the yield did not increase with mulch rate, but was maximum for mulch rate of 5.25 t/ha, after which, yield gradually decreased with increasing mulch rate. Good crop growth requires appropriate conditions of air, heat and so on. Too large mulch rate hinders soil ventilation and lowers soil temperature too much, both of which adversely affects crop growth and yields. Consequently, the mulch rate should be aimed to save water and increase yield. So there exists an optimal mulch rate, which, under the condition of this experiment was about 5.25 t/ha.

CONSERVING WATER AND SOIL AMELIORATION

Proper application of a wheat-straw/corn-stalk mulch layer over the soil prevents direct impingement of storm water on erosion of the soil surface, increases the rate of water infiltration into the soil, reduces overland runoff, so that more rainwater is received, soil erosion can be controlled, and soil hardening from irrigation can be prevented. As the mulch layer over the soil impedes evaporation of soil water, so that accumulation of salinity near the soil surface is prevented. Our field investigation revealed that the wheat-straw/corn-stalk mulch began to rot soon after it meets water, from below to above, with the bottom part turning black, and the surface part still being yellow. There were many earthworms in the mulched soil. Wheat-straw/corn-stalk contains various nutritious elements (N, P, K), which can add nutrient to soil, and so, is soil manure after being returned to the field.

CONCLUSIONS

Our series of field paired experiments with and without mulch for both winter wheat and summer corn, led us to reach some conclusions as follows:

1. Wheat-straw/corn-stalk mulch in the field plays an obvious water saving role, and considerably enhances the utility factor of field water.

2. Day and night variations of soil temperature in the cultivation layer present waveform curves, whose amplitudes decrease with increase in soil depth, and phase lag with depth.

3. Wheat-straw/corn-stalk mulch can increase yields of summer corn and winter wheat.

4. Mulch can considerably restrain weeds from breeding. Weeds hardly exist in the field when the mulch rate exceeds 5.25 t/ha.

5. The suitable mulch rate should be assessed by both water saving and yield increase. The optimal mulch rate is about 5.25 t/ha in our experiment.

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