

## Water Consumption Characteristics and Economic Benefits of Intercropped Farmland under Two-Year Plastic Film Mulching at Different Irrigation Levels: Postprint

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### Abstract

Using the dominant maize||pea intercropping system in the Hexi Corridor region as the research object, this study investigated the effects of two-year plastic film mulching, autumn no-tillage with spring mulching, and conventional tillage with mulching on water consumption and inter-plant evaporation in intercropping populations under three irrigation levels: high (7 200 m<sup>3</sup> · hm<sup>2</sup>), medium (6 450 m<sup>3</sup> · hm<sup>2</sup>), and low (5 700 m<sup>3</sup> · hm<sup>2</sup>), aiming to provide a theoretical basis for optimizing tillage measures, plastic film reuse, and improving water use efficiency in intercropping systems. The results showed that different irrigation levels had significant effects on inter-plant evaporation during the growth period of intercropping populations, with evaporation increasing as irrigation level increased; however, differences among different mulching methods were not significant at the same irrigation level, and the interaction effect was not significant. Before and after pea harvest, inter-plant evaporation in intercropped farmland showed significant differences between maize strips and pea strips across different treatments, with the average evaporation in pea strips being 68.51% and 69.30% higher than that in maize strips before and after harvest, respectively. Pea strips were the main factor causing high evaporation water consumption in the intercropped farmland system, with maize strips occupying 60% of the land area contributing only 44.47% of total farmland evaporation, whereas pea strips occupying merely 40% of the land area contributed 55.53%. Inter-plant evaporation in maize-pea intercropped farmland occurred mainly after pea harvest, with evaporation before pea harvest accounting for only 26.98% of total evaporation. Two-year plastic film mulching could significantly improve economic benefit per unit water, with the average across different irrigation treatments increasing by 7.39% and 31.33% compared with autumn no-tillage with spring

mulching and conventional tillage with mulching, respectively, and the highest economic benefit per unit water of 2.51 yuan · m<sup>3</sup> achieved under medium irrigation conditions. The study results indicated that under the same irrigation level, two-year plastic film mulching in maize strips had comparable effects to traditional mulching methods in suppressing inter-plant evaporation and reducing ineffective water loss; inter-plant evaporation and water consumption structure (E/ET) were positively correlated with irrigation level; and two-year plastic film mulching could obtain higher economic benefits under medium irrigation levels.

## Full Text

### 1.1 Overview of the Experimental Area

This study was conducted at the Oasis Agriculture Research and Teaching Base of Gansu Agricultural University (103°5 E, 37°30 N). The experimental site is located in Huangyang Town, Liangzhou District, Wuwei City, at the eastern end of the Hexi Corridor, characterized by a cold temperate arid climate. The altitude is 1,506 m, the frost-free period is approximately 155 days, the multi-year average rainfall is 156 mm, the annual evaporation is about 2,400 mm, the aridity index is 5.85, and the annual average temperature is 7.2 °C. The accumulated temperatures of  $\geq 0$  °C and  $\geq 10$  °C are 3,513.4 °C and 2,985.4 °C, respectively, and the sunshine duration is 2,945 hours. The area has vast land resources, abundant light resources, and large diurnal temperature differences, making it suitable for developing multi-cropping systems such as intercropping. During the experimental period, the effective rainfall was 216.6 mm, and the average daily temperature in the experimental area was 17.85 °C (Fig. 1 [Figure 1: see original paper]).

### 1.2 Experimental Design

The experiment consisted of three mulching and tillage methods: conventional mulching and tillage, no-tillage in autumn with mulching in spring, and one-film-for-two-years mulching; and three irrigation gradients: irrigation quotas of 5,700 m<sup>3</sup> · hm<sup>-2</sup>, 6,450 m<sup>3</sup> · hm<sup>-2</sup>, and 7,200 m<sup>3</sup> · hm<sup>-2</sup>, with the irrigation schedule formulated according to the growth stages of maize. There were nine treatments in total, with three replications arranged randomly in the field. The design and implementation methods for different treatments are shown in Table 1, and the irrigation schedules are shown in Table 2 .

Fertilization regime: The total nitrogen application rate was consistent across all treatments at 300 kg · hm<sup>-2</sup>, with 10% applied as basal fertilizer. Topdressing was applied according to maize growth stages: the first topdressing at the jointing stage (six-leaf stage) accounted for 20% of total nitrogen; the second at the large bell mouth stage (ten-leaf stage) accounted for 50%; and the third was applied 10 days after maize flowering, using the remaining nitrogen. Phosphorus fertilizer was applied entirely as basal fertilizer at an N:P ratio of 1:0.75.

## 1.3 Field Structure and Stubble Treatment

### 1.3.1 Field Structure

Maize||pea intercropping was implemented in strip patterns, with the maize strip mulched with plastic film and the pea strip left unmulched. The maize strip was 110 cm wide with three rows, while the pea strip was 80 cm wide with four rows.

### 1.3.2 Stubble Treatment

The pea (*Pisum sativum*) variety was ‘Longwan No. 1’ . Peas were sown on April 5, 2014, and harvested on July 10, 2014; maize was sown on April 25, 2014, and harvested on October 1, 2014.

According to the experimental design, plots under the one-film-for-two-years treatment and the autumn no-tillage with spring mulching treatment were left untilled after maize harvest in 2013, maintaining plastic film integrity above 70%. The conventional tillage treatment involved residual film removal and deep plowing after maize harvest. In spring 2014, the autumn no-tillage with spring mulching treatment removed the old film before rotary tillage and mulching, while the conventional mulching treatment performed rotary tillage and harrowing before mulching. All measurements were taken in 2014.

## 1.4 Measurement Indicators and Methods

### 1.4.1 Soil Evaporation Between Plants

The experiment was conducted in 2013 and 2014, with 2013 serving as a preliminary trial where irrigation, fertilization, and other field management practices for maize||pea intercropping were kept consistent. The maize variety was ‘Xi-anyu 335’ .

Self-made micro-lysimeters (Micro Lysimeter, constructed using PVC pipes with a diameter of 10 cm and height of 15 cm, sealed at the bottom with plastic film) were placed in pre-installed tubes in the field with their tops flush with the ground surface. In the maize||pea intercropping system, one micro-lysimeter was installed in each of the pea and maize strips to measure soil evaporation separately. The pre-installed tubes were positioned in the center of each strip, with the tube center 20 cm from maize plants on both sides in the maize strip, and 10 cm from pea plants on both sides in the pea strip (Fig. 2 [Figure 2: see original paper]). Soil evaporation was calculated by weighing daily using an LP3102 electronic balance with a precision of 0.02 g. A weight reduction of 1 g in the micro-lysimeter corresponded to 0.1051 mm of water evaporation. Undisturbed soil samples from the plots were used for measurements, taken every 3 days. The soil in the lysimeters was replaced every 2-3 days to maintain consistency with field soil moisture, with additional measurements taken after rainfall or irrigation. In this study, the pre-pea-harvest period was calculated

from pea sowing on April 5 to pea harvest on July 10, while the post-pea-harvest period spanned from July 10 to maize harvest on October 1. The intercropping system's total soil evaporation was calculated using the weighted average method based on the land area proportion of the two crops.

#### 1.4.2 Soil Water Content

Soil water content was measured using a soil auger and a neutron moisture gauge. Measurements were taken every 20 days, with additional measurements before sowing, after harvest, before irrigation, and after irrigation. The measurement depth was 120 cm. For the 0–30 cm layer, soil samples were manually collected with an auger at 10 cm intervals. The 30–120 cm layer was measured using a neutron moisture gauge (503DR, CPN Corporation, USA). One measurement point was established in each of the maize and pea strips, with aluminum tubes installed in the center of each strip (Fig. 2).

#### 1.4.3 Crop Water Consumption (ET)

Crop water consumption (ET) was calculated as:

$$ET = (\text{soil water storage before sowing} - \text{soil water storage after harvest}) + \text{precipitation during the growth period}$$

Given the relatively small irrigation amounts in this experiment and scarce precipitation during the trial period, deep percolation was considered negligible. With groundwater depth exceeding 30 m, upward capillary rise from groundwater was also not considered. The formula is:

$$ET = P + I + S_1 - S_2$$

where  $P$  is precipitation during the growth period,  $I$  is irrigation amount,  $S_1$  is soil water storage at sowing, and  $S_2$  is soil water storage at harvest.

Soil water storage (SWS, mm) in the 0–120 cm layer was calculated using the following formula:

$$SWS = h \times a \times \theta \quad (2)$$

where  $h$  is soil depth (cm),  $a$  is soil bulk density ( $\text{g} \cdot \text{cm}^{-3}$ ), and  $\theta$  is volumetric water content.

#### 1.4.4 Yield Measurement

Yield was determined for each experimental plot by harvesting and threshing separately, followed by natural air-drying.

#### 1.4.5 Water Benefit per Cubic Meter

Water benefit per cubic meter was calculated as:

$$\text{Water benefit per cubic meter} = \text{Net benefit} / \text{Water consumption}(ET) \quad (3)$$

$$\text{Net benefit} = \text{Total output value} - \text{Total input} \quad (4)$$

Prices for agricultural products (grain, straw) and production inputs (seed, pesticide, fertilizer, plastic film, labor, machinery) were calculated based on the average market prices for that year.

### 2.1 Effects of One-Film-for-Two-Years Mulching on Soil Evaporation

Total soil evaporation during the entire growth period of the maize||pea intercropping system under different irrigation levels and mulching conditions was calculated using the weighted average method, as shown in Fig. 3 [Figure 3: see original paper]. Irrigation level had a significant effect on total soil evaporation in the intercropping system, but differences among mulching methods were not significant at the same irrigation level, and the interaction effect was not significant. Different lowercase letters in the figure indicate significant differences among treatments at the 5% level, the same below.

Under the one-film-for-two-years treatment (NT), the high irrigation treatment (I3) and medium irrigation treatment (I2) showed soil evaporation 28.25% and 20.97% higher than the low irrigation treatment (I1), respectively, with significant differences between the high irrigation level and the medium/low levels. Under the autumn no-tillage with spring mulching treatment (RT), the high irrigation treatment (I3) exhibited soil evaporation 27.44% and 38.60% higher than the medium (I2) and low (I1) irrigation treatments, respectively, with significant differences among irrigation levels. Under the conventional tillage treatment (CT), significant differences existed among the three irrigation levels, with the high (I3) and medium (I2) irrigation treatments showing 37.02% and 22.51% higher soil evaporation than the low irrigation treatment (I1), respectively.

These results indicate that one-film-for-two-years mulching and conventional mulching had similar effects on soil evaporation, with differences in evaporation primarily caused by varying irrigation amounts.

### 2.2 Spatiotemporal Distribution Characteristics of Soil Evaporation in Maize||Pea Intercropping Fields with One-Film-for-Two-Years Mulching

**2.2.1 Soil Evaporation in Different Crop Strips Before and After Pea Harvest** Total soil evaporation in different crop strips before pea harvest in the maize||pea intercropping system is shown in Fig. 4 [Figure 4: see original

paper]. Significant differences in soil evaporation existed between maize and pea strips before pea harvest, with pea strip evaporation 68.51% higher than that in maize strips. Evaporation in pea strips under high irrigation treatments NTI3, RTI3, and CTI3 reached 96.70 mm, 95.65 mm, and 95.50 mm, respectively, while evaporation in maize strips under the same high irrigation treatments was only 54.30 mm, 57.80 mm, and 57.70 mm, representing reductions of 43.85%, 39.57%, and 39.58% compared to pea strips.

Before pea harvest, soil evaporation in maize strips under one-film-for-two-years mulching (NT) was 10.91% and 17.84% higher than under autumn no-tillage with spring mulching (RT) and conventional mulching (CT), respectively. Under the same mulching method, significant differences in soil evaporation among irrigation levels were observed in each strip before pea harvest. In maize strips, NTI3 was 2.55% and 7.10% higher than NTI2 and NTI1, respectively; RTI3 was 27.78% and 35.52% higher than RTI2 and RTI1; and CTI3 was 34.03% and 72.04% higher than CTI2 and CTI1, respectively.

These results demonstrate that while one-film-for-two-years mulching (NT) in maize strips significantly reduced soil evaporation compared to pea strips, evaporation was higher than under RT and CT treatments, primarily because soil moisture content before pea harvest was significantly higher under NT than under RT and CT. Additionally, higher irrigation levels led to greater soil evaporation, resulting in increased ineffective water loss.

Soil evaporation differences after pea harvest are shown in Fig. 5 [Figure 5: see original paper]. Soil evaporation after pea harvest was significantly higher than before pea harvest, with significant differences between maize and pea strips. Evaporation in pea strips after harvest was 69.30% higher than in maize strips on average. Pea strip evaporation under high irrigation treatments NTI3, RTI3, and CTI3 reached the highest values of 312.25 mm, 301.05 mm, and 310.50 mm, respectively, while maize strip evaporation under the same treatments was only 168.25 mm, 169.20 mm, and 168.70 mm, representing reductions of 46.12%, 43.80%, and 45.67% compared to pea strips.

At the same irrigation level, no significant differences in soil evaporation were observed among mulching methods. The average evaporation across three irrigation levels was 153.95 mm for NT, 146.90 mm for RT, and 143.3 mm for CT. These results indicate that post-pea-harvest evaporation constituted the major portion of total field evaporation, and that plastic film mulching in maize strips significantly reduced soil evaporation, with one-film-for-two-years mulching having the same inhibitory effect as conventional mulching.

**2.2.2 Total Soil Evaporation Before and After Pea Harvest** Total soil evaporation before and after pea harvest is shown in Fig. 6 [Figure 6: see original paper]. Soil evaporation in maize||pea intercropping systems occurred mainly after pea harvest, with pre-harvest evaporation accounting for only 26.98% of total evaporation. Post-harvest evaporation increased by 174.34%, 173.12%, 169.82%,

169.55%, 168.43%, 170.51%, 159.37%, 186.84%, and 165.10% compared to pre-harvest evaporation for treatments NTI3, NTI2, NTI1, RTI3, RTI2, RTI1, CTI3, CTI2, and CTI1, respectively, with significant increases. At the same irrigation level, different mulching methods showed no significant differences in total evaporation before or after pea harvest. However, under the same mulching condition, irrigation level had a significant effect on evaporation, with medium and high irrigation levels showing significantly higher total evaporation than the low level both before and after pea harvest. This demonstrates that one-film-for-two-years mulching can achieve the same evaporation reduction effect as conventional mulching.

**2.2.3 Proportion of Evaporation in Intercropping Strips** The proportion of soil evaporation in maize and pea strips relative to total evaporation in the intercropping system is shown in Fig. 7 [Figure 7: see original paper]. The proportion of evaporation from maize strips was significantly lower than that from pea strips. Under high irrigation, maize strip evaporation accounted for 42.62%, 44.03%, and 43.40% of total evaporation in treatments NTI3, RTI3, and CTI3, respectively, while pea strips accounted for 57.38%, 55.97%, and 56.60%. Under medium irrigation, maize strips accounted for 47.17%, 47.01%, and 41.11% in NTI2, RTI2, and CTI2, respectively, while pea strips accounted for 52.83%, 52.99%, and 58.89%. Under low irrigation, maize strips accounted for 47.56%, 44.62%, and 42.68% in NTI1, RTI1, and CTI1, respectively, while pea strips accounted for 52.44%, 55.38%, and 57.32%.

Calculations based on total evaporation and land area proportions revealed that maize strips, occupying 60% of the farmland, contributed only 44.47% of total field evaporation, whereas pea strips, occupying just 40% of the area, contributed 55.53% of total evaporation. This indicates that unmulched pea strips were the primary source of soil evaporation in the intercropping system, and higher irrigation rates led to greater ineffective water loss through evaporation in pea strips.

### **2.3 Effects of One-Film-for-Two-Years Mulching on Water Consumption Structure**

In crop production, reducing the proportion of soil evaporation in total crop water consumption ( $E/ET$ ) through agronomic techniques such as plastic film mulching is an important means of improving water use efficiency. Water consumption of the intercropping system was calculated using the weighted average method, and the water consumption structure ( $E/ET$ ) was determined. The  $E/ET$  values for maize||pea intercropping under different irrigation levels and mulching conditions throughout the growth period are shown in Fig. 8 [Figure 8: see original paper]. No significant differences in  $E/ET$  were observed among mulching methods. Across different irrigation levels,  $E/ET$  values decreased with decreasing irrigation level. This indicates that excessive irrigation increased field evaporation losses, while appropriate irrigation effectively

reduced ineffective water loss from evaporation while maintaining crop yields.

#### 2.4 Effects of One-Film-for-Two-Years Mulching on Grain Yield and Water Benefit

As shown in Table 3, the one-film-for-two-years mulching pattern (NT) effectively improved water benefit per cubic meter, with increases of 7.39% and 31.33% compared to autumn no-tillage with spring mulching (RT) and conventional mulching (CT), respectively. Under the same mulching method, significant differences existed among irrigation treatments, with the medium irrigation level (I2) showing the highest benefit, followed by the high level (I3), and the low level (I1) showing the lowest. The medium irrigation level under one-film-for-two-years mulching achieved the highest water benefit per cubic meter at  $2.51 \text{ Yuan} \cdot \text{m}^{-3}$ , with NTI2 showing 8.86% and 45.94% higher water benefit than NTI3 and NTI1, respectively. This demonstrates that one-film-for-two-years mulching in maize||pea intercropping fields can reduce resource input costs and significantly improve water benefit per cubic meter under appropriate irrigation levels. Different lowercase letters in the same column indicate significant differences among treatments at the 5% level.

### 3 Discussion and Conclusion

Soil evaporation between plants is a purely physical process of soil water loss in fields and represents ineffective water consumption. The magnitude of soil evaporation is closely related to soil water content, solar radiation, air temperature, and plastic film mulching conditions. In oasis irrigation areas of northwest China, annual evaporation exceeds annual rainfall by more than 15 times. Therefore, the key to water saving in these oasis farmlands lies in maximizing the reduction of soil evaporation through scientific agricultural measures. Plastic film mulching can reduce soil water evaporation and decrease total water consumption[18]. Different irrigation amounts under plastic film mulching affect soil evaporation, with both evaporation and evapotranspiration increasing as irrigation amount increases[19]. This study demonstrated that in maize||pea intercropping systems, soil evaporation increased with irrigation level but showed no significant correlation with mulching method, indicating that one-film-for-two-years mulching in maize strips could achieve the same water evaporation suppression effect as conventional mulching. Reduced tillage in pea strips had no obvious effect on evaporation. Unmulched pea strips were the primary factor causing high evaporation water consumption in the intercropping system, with maize strips occupying 60% of farmland but contributing only 44.47% of total field evaporation, while pea strips occupying just 40% of the area contributed 55.53% of total evaporation.

Further research on soil evaporation before and after pea harvest in intercropping fields revealed that evaporation after pea harvest was significantly higher than before harvest, with pea strip evaporation significantly exceeding that of maize strips after harvest—69.30% higher. This may be attributed to the small

shading area and large exposed ground surface of pea populations in the early stage, while maize strips benefited from plastic film mulching[20], which effectively blocked water exchange between the soil surface and atmosphere. Additionally, the larger leaf area index and stronger transpiration of maize populations in the later growth stage weakened evaporation. Thus, reducing soil evaporation in unmulched pea strips under one-film-for-two-years mulching in maize strips will be key to decreasing total evaporation in maize||pea intercropping fields. Hu et al.[21] found that straw mulching in wheat strips of wheat-maize intercropping systems reduced evaporation by 5.4%-10.0% and decreased E/ET by 2.9%-5.2% compared to no mulching, thereby reducing ineffective water loss and improving water use efficiency. Zhang et al.[2] also demonstrated that optimizing planting patterns, irrigation methods, irrigation schedules, and mulching approaches can effectively reduce ineffective evaporation between crops. Therefore, integrating one-film-for-two-years mulching technology in maize strips with straw mulching in pea strips in maize||pea intercropping systems shows potential for further reducing ineffective evaporation, though the mechanisms of this dual mulching technology in suppressing soil evaporation and reducing ineffective water loss require further investigation.

Meanwhile, one-film-for-two-years mulching technology can reduce production inputs and significantly improve economic benefits[22]. In this study, one-film-for-two-years mulching reduced machinery, labor, and plastic film inputs, effectively lowering production costs and significantly improving water benefit per cubic meter—by 7.39% and 31.33% compared to autumn no-tillage with spring mulching and conventional mulching, respectively. The highest water benefit per cubic meter ( $2.51 \text{ Yuan} \cdot \text{m}^{-3}$ ) was achieved under medium irrigation conditions with one-film-for-two-years mulching. Therefore, one-film-for-two-years mulching technology in maize strips of maize||pea intercropping systems should be a research priority for developing cost-effective intercropping models in arid regions.

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