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Year-round plastic film mulch to increase wheat yield and economic returns while reducing environmental risk in dryland of the Loess Plateau

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ABSTRACT

In the coming decades, humanity will face great challenges in ensuring food and environmental security while reducing poverty through increasing economic profits. Plastic film mulch is an effective management practice for ensuring food security by improving crop productivity per unit area. However, its effects on environmental and economic benefits have not been well evaluated. Here, a location-fixed field experiment was performed to determine the effect of year-round plastic film mulch (YPM, mulching soil surface with plastic film during the growing season and fallow season of winter wheat) on wheat yield, environment (nitrate-N leaching and greenhouse gas (GHG) emissions), and economic returns. Compared with farmer practice (the local traditional practice), adoption of YPM increased the mean yield by 11%, which is attributed to the fact that YPM increased soil water storage at wheat sowing and soil temperature during wheat growing season by a mean of 7% and 0.6 °C, respectively. The increased grains induced a 12% increase in net economic returns. The YPM decreased the soil nitrate-N leaching by 51%, which was explained by decreasing soil nitrate-N residue caused by the increased yield. The YPM also reduced GHG emissions intensity by an average of 12%. As a result, YPM was a better choice for increasing yield and economic returns while reducing environmental risk. In the future, we should develop better mulching systems to further improve food, environmental benefits, and economic returns in dryland farming production.

1. Introduction

Dryland accounts for about 41% of the planet's land area, and dryland agriculture supply more than 38% of the world's food production (Reynolds et al., 2007; Stewart et al., 2006). The Loess Plateau, located in northwestern China, is a typical dryland agriculture region. Here, due to the lack of surface water and groundwater, insufficient annual precipitation (200–600 mm) is the only source of water (Zhang et al., 2011), the absence of soil water is therefore the most fundamental factor limiting crop productivity. In this region, winter wheat (*Triticum aestivum* L.)-summer fallow is the most common cropping system. More than 50% of precipitation occurs during summer fallow (Deng et al., 2006), the mismatch between the most important rainy season and growing season of winter wheat aggravates the water stress of wheat growth.

Plastic film mulch is an effective practice for improving soil water content, alleviating water stress, and increasing wheat yield, thus it has been widely applied in dryland wheat production (Li et al., 2004; Sharma et al., 2011). Due to adoption of plastic film mulch, wheat yield increased by 29% and 5% in western China and in Pakistan, respectively (Rehman et al., 2009; Xie et al., 2005). However, the plastic film mulch practices as these studies were usually only applied during growing season of wheat. Just because of failed to manage fallow season, this may not fully tap the potential of plastic film mulch to increase yield. In order to further improve yield, a year-round plastic film mulch (YPM), covering topsoil using clear plastic film through whole year (including growing season and summer fallow of winter wheat), was designed and conducted in this study.

For a long time, increasing yield has received greater attentions due to high demand for food, particularly for dryland regions with low yield (Ren et al., 2016). A series of environmental issues with the increased yield have been overlooked. Soil nitrate-N leaching and greenhouse gas (GHG) emissions are the typical environmental damage in wheat production systems (Cuello et al., 2015; Ju et al., 2009). In northern China, a survey of nitrate-N concentrations in groundwater confirmed that almost half of groundwater samples exceeded the WHO drinking water standards (Ju et al., 2006). Nitrate-N leaching should be responsible for this. In the Loess Plateau, the soil surface of farmland was usually bare

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during the summer fallow of winter wheat, and a heavy rainfall over a short time usually induced nitrate-N leaching (Yang et al., 2015). In this study, we hypothesis that covering soil surface during summer fallow using plastic film has the capacity to decrease nitrate-N leaching and attempts to verify it by a location-fixed field experiment. In dryland, adoption of plastic film mulch to alleviate the limitation of soil water for crop growth is a helpless choice, since it requires extra inputs, including material of plastic film and machinery. The production and application of plastic film and the diesel consumption by machinery would induce GHG emissions (Wang et al., 2017). Although plastic film mulch has the ability to increase yield, it is still unclear whether it can reduce GHG emissions intensity (GHG emissions per unit yield).

Apart from food and environment benefits, economic returns play a predominant role in evaluating the feasibility of new technologies. Farmers often carefully consider inputs and outputs before using a new technology, because they have little capacity of undertaking the economic risk (Zhang et al., 2015a). In pursuit of economic returns, new technologies are mostly applied for high value-added agricultural products, such as strawberries (Steinmetz et al., 2016), whereas it is usually omitted for low value-added products like wheat, particularly for YPM system with costs increase. However, it is still unknown whether YPM application can increase the net economic returns in dryland wheat production systems. Overall, the yield, environmental impacts, and economic returns associated with YPM system in different precipitation levels is unclear. The objectives of this study were to: (1) detect YPM effect on wheat yield depending on soil water and soil temperature, (2) quantify environmental risk (soil nitrate-N leaching and GHG emissions intensity) and economic returns associated with YPM application, and (3) estimate the feasibility of adopting YPM in dryland wheat production in terms of yield, environmental risk, and economic returns.

2. Materials and methods

2.1. Site description

A location-fixed field experiment was established in 2008 at Changwu (35.20 °N, 107.75 °E, and 1200 m above sea level), located in the central Loess Plateau. As groundwater (50–80 m depth) is not used for crop production, precipitation is the only source of water. The precipitation over the seven consecutive experimental years and their long-term average were shown in Table 1. The annual mean air temperature is 9.1 °C. The soil at this experimental site is a silt loam texture, with a pH of 8.18, organic carbon of 0.853%, total N of 0.077%, nitrate-N of 13.1 mg kg^{-1}, available Olsen-phosphorus (P) of 4.50 mg kg^{-1}, and available potassium (K) of 130 mg kg^{-1}.

2.2. Experiment establishment

The field experiment designed and tested two treatments: farmer practice (the local traditional practice) and year-round plastic film mulch (YPM). For farmer practice, winter wheat was planted using traditional flat way without covering soil surface during wheat growing season; after the harvest of wheat, removing wheat straw from the field and ploughing the soil to a depth of 40 cm were performed. For YPM, alternating ridges and furrows were shaped on soil surface before wheat sowing, and the ridges were covered using a clear plastic film and the furrows were bare for seeding. The wide of ridge and furrow was 40 cm and 20 cm, respectively. The innovations of YPM reflected the management of soil surface during summer fallow. After the harvest of wheat, the plastic films were still remained on the ridges, and the shredded straws were returned to the furrows to cover topsoil. Until the end of summer fallow (i.e., before the beginning of subsequent wheat growing season), removing the plastic film from the ridges, ploughing the soil to a depth of 40 cm, and incorporating straw segments into soil were performed. This meant that soil surface in YPM has been covered throughout whole year.

The N fertilizer rates were 162 kg N ha^{-1} in all years for farmer practice, and 138 and 150 kg N ha^{-1} in 2008–2010 and 2010–2015 for YPM, respectively. In 2008–2012, three quarters of N fertilizer was used before wheat sowing, and one quarters of N fertilizer was used at the frozen soil melted (February 20 in 2009, March 8 in 2010, March 5 in 2011, and March 18 in 2012). In 2012–2015, all N fertilizers were used before wheat sowing. All N inputs of YPM and farmer practice in 2008–2015 were shown in Table S1. In all years for farmer practice and YPM, the P fertilizer rates were 105 kg P_2O_5 ha^{-1}, and applied before wheat sowing. Because soil available K supply is sufficient, no K fertilizer was applied in this study. In all years, the plots (22 m × 6 m) were arranged in a randomized block design with four replicates. The seeding rate of winter wheat was 150 kg ha^{-1}. Herbicides, fungicides, and insecticides were applied to control weeds, diseases, and pests each year.

2.3. Sampling and measurement

At the maturity period of winter wheat, the fresh grains for each plot were harvested using a combine harvester and weighed to obtain a fresh weight. ~1 kg fresh grains per plot was collected to calculate its water content, and thus obtain dry weight.

Soil samples from 0 to 300 cm profile were collected before sowing and after harvest of winter wheat each year to determine soil water

Table 1

Monthly precipitation (mm) at the experimental site in seven experimental years (2008–2015).

Month	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	Long-term average [b]
July	185[a]	135	207	127	100	259	31	110
August	57	97	211	111	146	57	139	107
September	108	47	77	227	75	106	181	98
October	19	19	27	52	10	32	18	51
November	11	9	0	54	0	23	9	20
December	0	0	0	4	0	0	0	5
January	0	0	0	0	0	0	8	6
February	21	34	14	13	3	21	7	9
March	21	19	18	17	9	31	34	23
April	11	45	8	38	25	97	65	39
May	64	39	70	50	69	35	42	54
June	15	31	34	29	10	46	104	58
Annual precipitation	513	475	666	722	447	706	638	580
Rainfall in fallow season	270	280	458	453	285	332	351	316
Precipitation in growing season	243	195	208	269	161	374	287	264

[a] Precipitation was obtained from a standard rain gauge installed at the experimental site.

[b] Long-term average represents the mean precipitation over 58 years from 1957–2015.