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Maize–fababean rotation under double ridge and furrows with plastic mulching alleviates soil water depletion

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ABSTRACT

Double ridge and furrows with plastic mulching (PM), an effective drought-resistant farming technology, has been widely used in the semi-arid areas of China, and increased crop yields by more than 30%. However, where this technology has been applied in successive years, the annual balance of soil water has been affected and the risk of soil desiccation exacerbated. A 6-year field experiment had been conducted on the semiarid Loess Plateau to find a new mode of ecological security and economic efficiency under PM conditions. The two treatments were (i) PM with continuous maize cropping (PM-C) and (ii) PM with maize–fababean rotation (PM-R). The vertical variation of soil water along profile and the interannual variation of soil water, cumulative water consumption, biomass and yield, benefit and water economic yield were investigated. The results showed that the depth of soil water consumption of PM-C was extended downward by 60 cm from 2009 to 2014, but it did not vary in PM-R; the maximum depth of soil water consumption were 280 cm and 220 cm in PM-C and PM-R, respectively. Compared with the pre-seeding stage in 2009, soil water storage in the 0–300 cm depth in 2014-HA for PM-C decreased by 163.59 mm, comprising 5.21 mm in the 0–140 cm soil layer and 158.37 mm in the 140–300 cm layer. However, in the PM-R treatment, the soil water storage in the 0–300 cm depth in 2014-HA increased by 28.36 mm, resulting from an increase of 47.86 mm in the 0–140 cm soil layer and a decrease of 19.50 mm in the 140–300 cm layer. PM-R significantly improved crop water consumption in the post-flowering period, and the ratio of water consumption in post-flowering to total significantly increased by 19.54–51.09% ($P < 0.05$). The biomass and grain yield for PM-R were significantly lower than for PM-C, by 21.36 and 59.14%, respectively. However, there were no significant differences in benefit, mainly because the price of fababean was higher. The soil water depletion in 6 years of PM-R decreased significantly and therefore water economic yield was significantly higher than for PM-C. This suggested that PM-R alleviated the over-consumption of deep soil water and the water depletion depth, which caused by continuous maize cropping in PM-C, and so achieved significantly higher water economic yield by reducing soil water depletion and provided stable economic benefit. Consequently, PM-R represents a sustainable ecological, economic, secure and replicable planting mode.

1. Introduction

There are 0.85 billion people living in hunger worldwide, mainly in developing countries, and the global food demand continues to increase (Sanchez and Swaminathan, 2005; Zhang et al., 2007; Sapna and Neeraj, 2014). The food self-sufficiency rate of China was 88.38% in 2012 (Tang, 2014), which was lower than the internationally recognized red line rate of > 95% (Wang et al., 2009). This food gap is huge, especially in poor areas, where average annual consumption of food per person is 195 kg, equivalent to 73.9% of the national average, and 36.4% of farmers cannot meet the basic ration demand (Zhang, 2011). Therefore, improving food production capacity in poor areas is essential to national food security. The food deficit in the northwest Loess Plateau of China is historical because of insufficient natural resources and a fragile ecological environment. Maize is the most important crop for grain production, but its yield does not exceed 4.5 t ha^{-1} when using traditional planting technology in this area (Fang et al., 2015). However, with the introduction of double ridge and furrows with plastic mulching technology in 2006, yield increased up to 8.81 t ha^{-1} (Wang et al., 2011a, 2013; Dong et al., 2017). During 2006–2013, the average annual increase of grain was 856,000 t in the northwest Loess Plateau of China, enough to feed 2.14 million people and increase income by 1.75 billion yuan. However, with the advent of plastic mulching, high water-consumption crops (e.g. maize) were planted continuously, threatening the interannual balance of soil water. The soil water storage capacity at depths below 2 m was reduced, the

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risk of soil desiccation increased and threatened the soil water ecology (Chen et al., 2008a, 2008b ; Wang et al., 2011a, 2012, 2013; Fan et al., 2014; Dong et al., 2017).

The ecologically negative effects of continuous maize cropping with plastic mulch have aroused the concern of many scholars, and it is necessary to find a new mode for ecological security and economic efficiency. Studies have shown that maize and other crop rotations can increase yields (Al-kaisi and Yin, 2004; Wilhelm and Wortmann, 2004), improve soil organic carbon input and improve land use efficiency (Gu et al., 2017). In addition, legume–cereal crop rotations and deep-–shallow root crop rotations are important measures to optimize soil water utilization (Li et al., 2008). The stable sown area of fababean is up to 96,000 ha in Gansu Province, accounting for about 40% of the area of fababean in China. Based on relatively low water consumption, high prices and strong nitrogen-fixing ability, it is frequently used for intercropping or rotation crops (Zhang et al., 2016; Hou et al., 2016). Therefore, this experiment selected fababean as a rotation crop for a rotation system of legumes–cereals, deep–shallow root, to alleviate the negative ecological effects of continuous maize cropping combined with mulching.

The regulation of water and nutrient in the pre- and post-flowering period is one of the main methods to optimize resource utilization and increase yield (Nishioka and Okumura, 2008; Dordas, 2009; Xie et al., 2016; Guo et al., 2016). Studies have shown that potato and legume intercropping can increase potato water uptake in the post-flowering period, significantly improve land productivity without negative effects on soil water sustainability (Zhang et al., 2016; Hou et al., 2016). The rotation adjusts water depletion processes in the pre- and post-flowering periods, thus affecting yield; however, there has been little relevant research. The soil water temporal-spatial variation, soil water depletion, biomass and yield, benefit, and economic water use efficiency (EWUE) of maize–fababean rotation were analyzed during 2009–2014. The effect of maize–fababean rotation on soil water depletion, economic benefit was evaluated, to clarify the function of rotation with mulching on the increase of land productivity and sustainability of interannual soil water storage on the Loess Plateau.

2. Materials and methods

2.1. Site description and the experimental treatments

This study site was located at the Dingxi Experimental Station of the Gansu Academy of Agricultural Sciences. The station is located in the northwest Loess Plateau (Anding District, Dingxi, Gansu Province, 104°36′E, 35°35′N) at an altitude of approximately 1970 m. Based on 35 years of records, mean annual rainfall is 415 mm with nearly 68% occurring during June–September, the relative variability of the precipitation is 24%, mean annual temperature is 6.2 °C. Average annual sunshine hours are 2500 h. The soil is a light loam of loess origin which belongs to lithological soil, organic matter content below 5%, without salinity and alkalinity problems. The soil water content (w/w) at field capacity and wilting point was 23 and 7.2%, respectively. Before this experiment conducted, the soil sample in 5 points had been collected randomly to measure the contents of soil organic matter, total nitrogen (N), total phosphorus, total potassium, ammonium-N, nitrate-N, available phosphorus and available potassium, it were 11.99 g kg $^{-1}$, 1.16 g kg $^{-1}$, 0.73 g kg $^{-1}$, 17.28 g kg $^{-1}$, 4.8 mg kg $^{-1}$, 0.8 mg kg $^{-1}$, 8.66 mg kg $^{-1}$ and 121.50 mg kg $^{-1}$, respectively.

In this study, two treatments were conducted during growing season from 2009 to 2014, that is, double ridge and furrows with plastic mulching with continuous maize cropping (PM-C), the maize continuously cultivated in 2009–2014 in this treatment. The double ridge and furrows with plastic mulching with maize–fababean rotation (PM-R), the maize and fababean rotated each year from 2009 to 2014 in this treatment. In two treatments, Maize was seeded 5–8 cm deep into soil with moisture content of 10–15% using a maize sower with 30 cm spacing in mid-April, giving a planting density of approximately 60,000 plants ha $^{-1}$. In PM-R treatment, Fababean was seeded 6–8 cm deep into soil with moisture content of 10–15% using a fababean sower with 8 cm spacing in mid–March, giving a planting density of approximately 225,000 plants ha $^{-1}$.

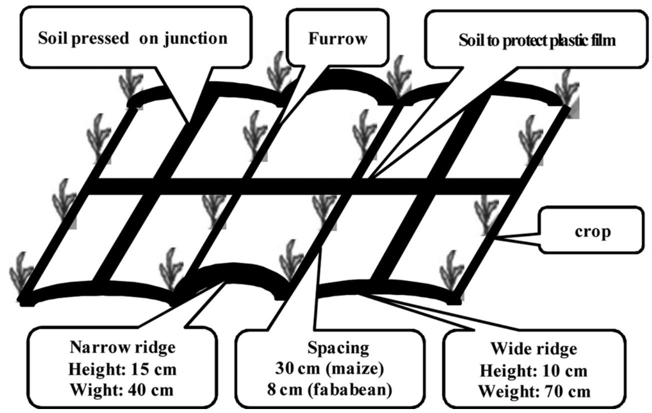

Fig. 1. Planting model of double ridge and furrows with plastic mulching.

The method of double ridge and furrows with plastic mulching comprised a wide ridge of height 10 cm and width of 70 cm and a narrow ridge of height 15 cm and width 40 cm, which were mulched with plastic film (Fig. 1) and seeds were sown in the furrow. All treatments were non–tillaged and plastic film was covered in place for all years. All treatments were arranged in a randomized complete design with three replications. The area of each plot was 6 m × 10 m = 60 m ^{2}. Maize were planted on April 20th and harvested on October 13th in 2009. Maize was planted on April 16th, harvested on October 16th; fababean were planted on March 15th, harvested on August 6th in 2010. Maize was sown on April 18th, harvested on October 15 in 2011. Maize was planted on April 20, harvested on October 21, fababean was sown on March 25, harvested on August 12 in 2012. Maize were sown on April 23, harvesting on October 13 in 2013. Maize were sown on April 17 and harvested on October 19, fababean were sown on March 20 and harvested on August 17 in 2014. The flowering period of maize is around July 23, and fababean is around May 28. Treatments received 225 kg N (maize) or 120 kg N (fababean) ha $^{-1}$, and maize and fababean received 150 kg P_2O_5 ha $^{-1}$, the fertilizer is applied once before sowing in each year

2.2. Precipitation and air temperature

Precipitation and air temperature according to come from meteorological data statistics at Dingxi Experimental Station of Gansu Academy of Agricultural Sciences.

2.3. Measurement of soil water storage

The soil water content (W_S) was measured at 20 cm step intervals in the 0–300 cm soil profile on six soil cores randomly collected from furrows in each plot. While the soil samples collected by drilling equipment and loaded into aluminum box, after the fresh weight weighed, the soil sample oven-dried at 105 °C for 8–10 h, and then measured the dry weight, the soil water content (%, w/w) calculated according to Formula (1). The soil water storage (SWS) calculated by Formula (2)

$$W_S = (\mathrm{FW} - \mathrm{DW})/(\mathrm{DW} - \mathrm{AW}) \quad (1)$$

where FW is fresh weight of soil sample with aluminum box, DW is dry weight of soil sample with aluminum box, AW is the weight of aluminum box.

$$\mathrm{SWS\ (mm)} = W_S \times b \times d \quad (2)$$