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RESEARCH ARTICLE

Soil mulching can mitigate soil water deficiency impacts on rainfed maize production in semiarid environments

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Abstract

Temporally irregular rainfall distribution and inefficient rainwater management create severe constraints on crop production in rainfed semiarid areas. Gravel and plastic film mulching are effective methods for improving agricultural productivity and water utilization. However, the effects of these mulching practices on soil water supply and plant water use associated with crop yield are not well understood. A 3-yr study was conducted to analyze the occurrence and distribution of dry spells in a semiarid region of Northwest China and to evaluate the effects of non-mulching (CK), gravel mulching (GM) and plastic film mulching (FM) on the soil water supply, plant water use and maize (*Zea mays* L.) grain yield. Rainfall analysis showed that dry spells of ≥5 days occurred frequently in each of 3 yr, accounting for 59.9–69.2% of the maize growing periods. The >15-d dry spells during the jointing stage would expose maize plants to particularly severe water stress. Compared with the CK treatment, both the GM and FM treatments markedly increased soil water storage during the early growing season. In general, the total evapotranspiration (ET) was not significantly different among the three treatments, but the mulched treatments significantly increased the ratio of pre- to post-silking ET, which was closely associated with yield improvement. As a result, the grain yield significantly increased by 17.1, 70.3 and 16.7% for the GM treatment and by 28.3, 87.6 and 38.2% for the FM treatment in 2010, 2011 and 2012, respectively, compared with the CK treatment. It's concluded that both GM and FM are effective strategies for mitigating the impacts of water deficit and improving maize production in semiarid areas. However, FM is more effective than GM.

Keywords: semiarid areas, plastic film mulching, gravel mulching, dry spell, evapotranspiration, maize yield

1. Introduction

Water and its efficient use are a growing major concern for agricultural production worldwide, particularly in dryland regions (Rockström *et al*. 2007; Vörösmarty *et al*. 2010). Approximately 18% of the Earth's land surface is semiarid land that is indispensable for global food production (UNEP 2007). Limited groundwater, low precipitation and high water losses combine to make water scarcity the main

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limiting factor for primary production in rainfed semiarid areas (Deng *et al*. 2006; Hatibu *et al*. 2006). However, some studies have indicated that an irregular temporal distribution and inefficient management of rainwater, rather than total rainfall, are the primary constraints on crop production (Barron *et al*. 2003; Rockström *et al*. 2010). Studies have reported that adopting optimized water and soil management strategies to bridge water limitations during dry spells can markedly promote crop growth and increase yields (Barron *et al*. 2003; Liu *et al*. 2010; Rockström *et al*. 2010; Nyakudya and Stroosnijder 2011; Li *et al*. 2013). With the population continuously growing, improving rainwater management to mitigate the negative impacts of water deficiency and increase water productivity in semiarid areas is crucial to ensuring future food security.

Soil surface mulching is a common and effective practice for offsetting water limitations in agricultural production. Gravel mulching (GM), an important traditional technique, has been used for many years worldwide (Lemon 1956; Modaihsh *et al*. 1985; Nachtergaele *et al*. 1998; Li 2003; Yamanaka *et al*. 2004; Li *et al*. 2005; Wang *et al*. 2011). In addition, plastic film, an artificial material, has also long been used (Clarkson 1960; Andrew *et al*. 1976). With the rapid development of modern industry, the use of plastic film mulching (FM) has greatly increased in recent years (Li *et al*. 2001, 2013; Anikwe *et al*. 2007; Liu *et al*. 2009; Zhou *et al*. 2009, 2012; Sharma *et al*. 2011). Numerous studies, such as those mentioned above, have reported that both the gravel and plastic film mulching techniques can effectively alleviate a water deficit by capturing rainfall and reducing soil evaporation. This increases soil water availability and dramatically improves crop yields, particularly in dryland farming systems. However, crop response to water stress or water supply varies during different growth stages. Moser *et al*. (2006) reported that pre-anthesis drought delayed the maize silking stage and shortened the grain filling duration, leading to 13–32% lower grain yield compared with well-watered maize. On the mostly semiarid Loess Plateau of China (Li 2004), maize was found to be sensitive to water deficit during the stem-elongation stage, and limited irrigation at this stage could increase the grain yield and water use efficiency (WUE) (Kang *et al*. 2000). Zhang *et al*. (2014) reviewed research on management strategies and found that maize grain yield linearly increased with increases in pre-silking water use, whereas no relationship was found between yield and post-silking water use. These differences were primarily attributed to the uneven distribution of rainfall and changing plant water requirements during different growth stages. Few studies have focused on yield formation associated with soil water supply and crop water use during different growth stages of mulched crops (Liu *et al*. 2010). Progress in addressing this issue will be extremely beneficial for informing rainwater management strategies to improve crop production in rainfed semiarid areas.

We conducted a 3-yr field study on the Loess Plateau to explore the effects of gravel and plastic film mulch on rainfed maize systems; maize is one of the dominant crops in the region (Zhang *et al*. 2011). Our objectives were to (i) evaluate limitations on maize production due to the total rainfall and timing of dry spells and (ii) determine the effects of two mulching techniques on the soil water supply, plant water use and maize yield.

2. Results

2.1. Precipitation, reference evapotranspiration and dry spell

The precipitation during the maize growing season was 496 mm in 2010, 487 mm in 2011 and 363 mm in 2012, accounting for 84, 76 and 76% of the annual precipitation, respectively (Fig. 1). Compared with the long-term average (1957–2009), precipitation during the maize growing season was 70 mm higher in 2010, 61 mm higher in 2011 and 63 mm lower in 2012. However, the intra-annual distribution of precipitation in the 3 yr was as same as over the longer term, i.e., much more rain fell late in the growing season. From the sowing to the silking stage (middle of July), the precipitation was 96 mm in 2010, 150 mm in 2011 and 165 mm in 2012. In contrast, 399, 337 and 198 mm fell from the silking to the maturity stage. This pattern most likely caused severe water stress before the silking stage.

The diurnal reference evapotranspiration (ET_0) displayed large fluctuations during the maize growth season, ranging from 0.5 to 10.7 mm d^{-1} in 2010, from 0.5 to 8.6 mm d^{-1} in 2011 and from 0.9 to 8.3 mm d^{-1} in 2012. The ET_0 was generally higher early in the growing season than late in the growing season. From the sowing to the silking stage, the cumulative ET_0 was 371 mm in 2010, 408 mm in 2011 and 395 mm in 2012, accounting for 64, 69 and 68% of the total ET_0 over the whole growing season in 2010, 2011 and 2012, respectively (Fig. 1).

An analysis of daily precipitation indicated that dry spells occurred frequently in each of the three maize growing seasons (Table 1). The cumulative length of dry spells during the maize growing season was 114 d in 2010, 113 d in 2011 and 100 d in 2012, of which 56–62% occurred from sowing to silking. We assigned dry spells to one of four categories, according to duration. Within the four categories, the most common lengths were 5 d and 6–10 d, and they occurred five times before the silking stage over the three growing seasons. The 5-d and 6–10 d dry spells occurred three and five times after the silking stage, respectively, over the three