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Research paper

The effects of plastic-film mulch on the grain yield and root biomass of maize vary with cultivar in a cold semiarid environment

Lin Wang[a], Xiao Gang Li[a,*], Zhen-Huan Guan[a], Bin Jia[a], Neil C. Turner[b], Feng-Min Li[a]

[a] State Key Laboratory of Grassland and Agro-Ecosystems, Institute of Arid Agroecology, School of Life Sciences, Lanzhou University, 222 South Tianshui Road, Lanzhou 730000, China

[b] The UWA Institute of Agriculture and UWA School of Agriculture and Environment, The University of Western Australia, M082, Locked Bag 5005, Perth, WA 6001, Australia

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ABSTRACT

Plastic-film mulch is an agricultural technology widely used for maize (*Zea mays* L.) production in northern China, but the effects of the interaction between cultivar and plastic-film mulch on the grain yield and biomass production have not been studied. Five maize hybrids, Jinsui 4; Jixiang 1; Pingyu 8; Xianyu 335 and Yuyuan 5, were assessed in 2014 and 2015 in plastic-film mulched and non-mulched ridge-furrow plots in a cold semiarid environment. In 2014, the grain yield of the five cultivars varied from 685 to 898 $g\ m^{-2}$ with no mulch, and from 966 to 1228 $g\ m^{-2}$ under mulch. In 2015 (drier and warmer than in 2014), the grain yield varied from 179 to 353 $g\ m^{-2}$ without mulch, and from 548 to 1021 $g\ m^{-2}$ with mulch. By incorporating the variation in grain yield over cultivars, mulch treatments and cropping years, Jixiang 1 was the highest yielding cultivar: in 2014 the grain yield reached 898 $g\ m^{-2}$ under no mulch, compared to 1228 $g\ m^{-2}$ under mulch, while in 2015 the grain yield was 329 $g\ m^{-2}$ under no mulch compared to 1021 $g\ m^{-2}$ under mulch. Cultivar and mulch independently affected the aboveground biomass and harvest index of maize. Jixiang 1 attained high yields as a result of average aboveground biomass, but high harvest index. Differences in maize water use efficiency (grain yield per unit of evapotranspiration) as affected by mulch and cultivar paralleled those of grain yield due to minor effects of mulch and cultivar on growing-season evapotranspiration. The effects of plastic-film mulch on maize root biomass in the upper 0.6 m soil profile and root/shoot ratio varied with cultivar. Averaging years and mulch treatments, Jixiang 1 had the smallest root biomass in the upper 0.6 m soil layer and Jixiang 1 and Jinsui 4 had smaller root/shoot ratios than the other three cultivars. We conclude that the effects of plastic-film mulch on the grain yield, root biomass and root/shoot ratio varied significantly with cultivar. A moderate aboveground biomass and high harvest index may give satisfactory grain yield in plastic-film mulched or non-mulched fields in hydrothermally-limited areas. A wide variation of root/shoot ratio with maize cultivar and cropping year indicated that using a fixed root/shoot ratio to estimate the root carbon input to the soil would induce large uncertainty.

1. Introduction

Plastic-film mulching has become a globally applied agricultural practice (Steinmetz et al., 2016). In China, it is estimated that about 15–19% of its arable land is currently cultivated under plastic-film mulch (Wang et al., 2016a; He et al., 2017). Especially, in semiarid areas of China, plastic-film mulched ridge–furrow cropping has been extensively used for maize (*Zea mays* L.) production (Gan et al., 2013; Wang et al., 2016b). Under this system, soil water evaporation is reduced and soil temperature is increased. Precipitation on the mulched ridges is channeled into the furrows where the crop is sown (Jiang and Li, 2015). The improved soil hydrothermal conditions stimulate soil microbial activity and thus accelerate nutrient transformation (Zhang et al., 2012; Liu et al., 2014a; Wang et al., 2014; Hai et al., 2015). Thus, the improved soil hydrothermal conditions directly and indirectly increase crop productivity (Wang et al., 2016b).

Crop production requires an integration of biological and environmental factors. Differing genotypes differ in their capacities to overcome environmental stresses and capture resources for growth and grain formation (Tollenaar and Wu, 1999; Valentinuz and Tollenaar, 2004; Duvick, 2005; Ding et al., 2005; Luque et al., 2006; Acciaresi et al., 2014; Chen et al., 2013; Chen et al., 2015; Maheswari et al.,

* Corresponding author at: School of Life Sciences, Lanzhou University, 222 South Tianshui Road, Lanzhou 730000, China.
E-mail address: lixiaogang@lzu.edu.cn (X.G. Li).

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2016). For an increase in productivity, plant breeders seek to maximize yield of the economic crop components by selecting for these components under the appropriate environmental conditions. Therefore, selecting suitable cultivars to grow to maximize maize production in the plastic-film mulched ridge–furrow technology is an objective of both breeders and agronomists. However, currently maize breeding in China has not targeted the plastic-film mulch systems widely used in northern China, but is aimed at selection of cultivars adapted to a broad range of climatic and soil conditions (wide adaptation). It is not clear whether cultivars selected without plastic-film mulch and/or under irrigated conditions will yield well when grown under plastic-film mulch without irrigation.

The root system serves acquisition of nutrients and water from the soil and thus is vitally important for aboveground growth and grain yield formation. In water-limited environments, the importance of roots for acquisition of water has long been debated (Palta et al., 2011; Passioura, 1983); deep and prolific roots are considered beneficial, but there are some studies that suggest that roots can be too dense and costly in terms of carbon requirements, and root pruning to remove roots during vegetative development of winter wheat can increase yields (Fang et al., 2010). Root biomass is also an important source of soil organic carbon. Maintenance of soil organic carbon is a requirement for any sustainable agricultural technology (Godfray et al., 2010; Cui et al., 2013). Increasing soil temperature and moisture by the use of plastic-film mulch has been shown to increase soil organic carbon mineralization (Liu et al., 2014a; Wang et al., 2014; Wang et al., 2016a). However, the effects of plastic-film mulch on maize root biomass production and water use with cultivar have not been investigated. The ratio of root biomass to aboveground biomass (root/shoot) is a parameter used to assess total biomass partitioning between above- and belowground sections. Given a defined photosynthetic productivity, small root/shoot ratios favor the formation of grain and forage, but potentially lower soil carbon sequestration. However, the effects of using plastic-film mulching and thereby the improved soil hydrothermal conditions on crop root/shoot ratio in different cultivars of maize has never been reported.

The present study was designed to address: (1) whether the effects of plastic-film mulch on the aboveground biomass, yield, water use and water use efficiency of maize varies among cultivars; and (2) whether plastic-film mulch affects the root/shoot ratio among different maize cultivars. Answering these questions is important to maximize the benefits of using the plastic-film mulched ridge–furrow technology in maize production, and to provide a better understanding the interrelationships between crop and soil under the improved soil hydrothermal conditions.

2. Materials and methods

2.1. Study site, experiment design and management

The experimental was conducted in 2014 and 2015 in Yuzhong County, Gansu Province, China. The site (35°54′ N, 104°05′ E, altitude 2007 m above sea level) has a mean annual air temperature of 6.7 °C and a mean annual precipitation of 388 mm (from 1982 to 2013 recorded at the nearest weather station, about 10 km from the trial site, and 1890 m above sea level). The soil developed from loess is classified as Ustorthents (Soil Survey Staff, 1975). At the initiation of the experiment in 2014, the soil organic carbon concentration was 9.0 g kg^{-1}, total nitrogen 0.80 g kg^{-1}, mineral nitrogen 18 mg kg^{-1}, and Olsen phosphorus 10.4 mg kg^{-1} in the top 0.2 m. The soil pH was 8.2 (soil:water = 1:2.5) in the top 0.2 m. The bulk densities were 1.17, 1.29, 1.25, 1.14, 1.34, 1.24, 1.12 and 1.11 g cm^{-3} in the 0–0.2, 0.2–0.4, 0.4–0.6, 0.6–0.8, 0.8–1.0, 1.0–1.2, 1.2–1.4 and 1.4–1.6 m soil depths, respectively. The soil had silt loam texture throughout the 1.6 m profile, with a permanent wilting point of about 6.2% (Shi et al., 2003).

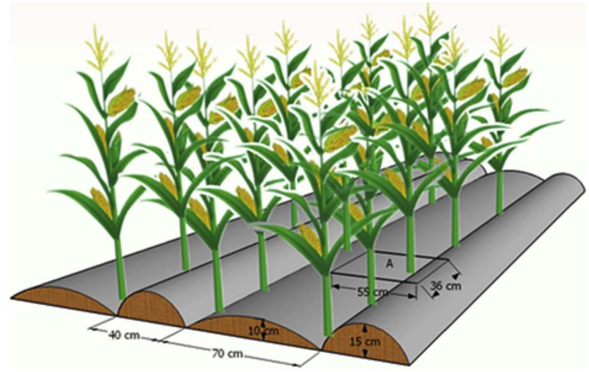

Fig. 1. Schematic of the ridge-furrow cropping system for maize, showing the 0.55 m × 0.36 m area used for each root sampling. The plants were sown in the furrows at a spacing of 0.36 m between plants.

The experiment was arranged in a randomized complete block design with two factors (2 mulch levels × 5 cultivars) and three replicates. Each plot measured 33 m^2 (5.5 m × 6 m). Five maize hybrids were assessed: Jinsui 4 (abbreviated as JS, released in 2005); Jixiang 1 (JX, 2011); Pingyu 8 (PY, 2012); Xianyu 335 (XY, 2010); and Yuyuan 5 (YY, 2013). These five cultivars were bred in China for grain production, and selected for a wide range of climatic and soil conditions. All five cultivars are grown by farmers near the experimental site as recommended by the local agricultural extension agency. Before mulching, urea (at 209 kg N ha^{-1}) and superphosphate (at 31 kg soluble phosphorus ha^{-1}) fertilizer was applied and then all plots were prepared in a ridge-furrow pattern with alternating narrow (0.15-m high × 0.4-m wide) and wide (0.1 m high × 0.7 m wide) ridges (Fig. 1). For the plastic-film mulch treatment, the entire ridge-furrow surface was covered immediately after preparation, with colorless and transparent 0.008-mm thick polyethylene film. After covering the soil with the plastic film, holes 15 mm in diameter and 0.20 m apart were punched through the film in the furrows. These holes and those made at sowing allowed rainwater from the ridges to enter the soil in the furrows (Liu et al., 2014b; Jiang and Li, 2015). After punching new holes in the furrows 0.36 m apart, a maize seed was placed in each hole (Fig. 1) on 14 April 2014 (23 days after the ridges were formed and mulched) and 20 April 2015 (32 days after ridges were formed and mulched). The purpose of preparing and mulching the ridges and furrows earlier than the maize sowing was to conserve soil moisture by reducing soil evaporation in the mulched plots. The experiment was located in the same field in 2014 and 2015. Each year, 10 rows of maize were hand sown in each plot to give a planting density of 50500 plants ha^{-1}. This planting density was used by farmers under recommendation of the local agricultural extension agency.

Weeds, diseases and insect pests were rare at the field site; therefore chemical control was not necessary. After the maize was harvested on 10 October 2014, the remaining aboveground parts of the maize were removed from all the plots. In the early November, the plastic-film mulch was removed and the soil was then ploughed to a depth of 0.15 m. The retention of the plastic-film mulch from harvest in early October to early November 2014, resulted in higher soil moisture in the mulched plots that persisted until sowing in 2015 (see the Results section). In 2015, each mulch treatment and cultivar was arranged in the same location as in 2014. Maize was harvested on 12 October 2015.

2.2. Measurements of air and soil temperature, precipitation and soil water content

Each year, the soil temperature was measured using button-type temperature recorders (WatchDog B100, Spectrum Technologies Inc. Aurora, IL. USA) on four randomly-selected plots (two mulched with plastic-film and two non-mulched). At sowing each temperature