Field Crops Research 203 (2017) 201–211

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Ridge–furrow with plastic film mulching practice improves maize productivity and resource use efficiency under the wheat–maize double–cropping system in dry semi–humid areas

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ARTICLE INFO

Article history:
Received 30 October 2016
Received in revised form
28 December 2016
Accepted 29 December 2016

Keywords:
Wheat–maize double–cropping system
Rainwater harvesting system
Sustainable development
Irrigation

ABSTRACT

Developing water–saving cultivation techniques is necessary to relieve the pressure of water demand under irrigation regions in dry semi–humid areas of China. Ridge–furrow with plastic film mulching (RFPFM), as a prospective rainwater harvesting system, has been widely adopted in rain–fed arid and semi–arid regions in northern China. However, it is unclear if RFPFM can be applied to wheat–maize double–cropping systems to increase the summer–maize yield and water use efficiency (WUE) in dry semi–humid areas to reduce the use of irrigation water. Three cultivation practices (traditional flat planting (CK), RFPFM and well irrigation planting (WI)) in combination with two nitrogen (N) rates (75 and 225 kg N ha^{-1}) and two cultivars were conducted to certify the potential role of RFPFM in increasing summer–maize yields, WUE, and N fertilizer use efficiency based on the double–cropping system. The results showed that the RFPFM practice hastened maize seeding emergence by 2 days and extended grain filling duration by 3–4 days in comparison with the CK practice. Aboveground biomass and N accumulation of maize plant were significantly higher under RFPFM and WI practices than the CK practice. The maize yield of RFPFM was similar to that of WI practice, and both practices increased the number of kernels per ear, 1000–kernel weight and grain yield compared to the CK practice. The RFPFM practice increased WUE by 29.2% and 70.5%, compared to the CK and WI practices, respectively, for the summer–maize season, averaged across two years. In addition, RFPFM practice significantly increased N fertilizer productivity and N uptake efficiency by 33.4% and 44.7%, respectively, in comparison with CK, averaged across other treatments and two years. The present study illustrates that the RFPFM practice could maintain the high summer maize productivity under wheat–maize double–cropping systems in dry semi–humid areas.

1. Introduction

Agricultural irrigation water resource depletion has been a long–term major issue and is becoming increasingly severe with the growing population and global climate change (Elliott et al., 2014). Food demand is continuously increasing, and with the agricultural water resource as the main factor affecting crop yield performance, it is necessary to produce larger quantities of grain with limited water resources. Increasing water productivity is considered to be the best method for achieving efficient water use for sustainable crop production in the future (Rodrigues and Pereira, 2009).

To ensure high and stable grain yield, a large volume of irrigation water has been used for agricultural production (Tang et al., 2015) in the irrigation regions of northwest China. In more recent years, due to the acceleration in industrialization and urbanization, water demand is rapidly increasing, which in turn increases competition for water among agricultural concerns, other industries and households (Jiang, 2009; Tang et al., 2015). Surface water and groundwater are two primary sources of irrigation water. Through their excessive application, these resources have become scarce in northwest China (Chang et al., 2016). Irrigation water scarcity is now a common issue limiting the sustainable development of

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http://dx.doi.org/10.1016/j.fcr.2016.12.029
0378-4290/

irrigation agriculture. Adopting water–saving agriculture countermeasures increases agricultural water productivity, making it essential in ensuring agricultural sustainability and food security.

The limited amount of irrigation water and unpredictable lows of precipitation during the growing period of crops in arid and semi–arid areas have led to the development of many agronomic technologies to conserve water and thereby to improve crop productivity; some examples include rainwater harvesting, gravel–sand mulch, crop residue retention, no–tillage farming systems, etc. (Gan et al., 2013; Qin et al., 2014). Among these technologies, ridge–furrow with plastic film mulching (RFPFM) is regarded as a high–efficiency rainwater harvesting system that can be developed in rain–fed farming systems in arid and semi–arid areas. The RFPFM system uses alternating furrows and ridges, with its ridges mulched using plastic film (Gan et al., 2013). Researchers have identified many advantages to this technology including preserving soil moisture in decreasing unproductive evaporation, prolonging the period of soil water availability to plants, penetrating collected light rain water into deep soil, building ridges along the farmland contours to reduce soil and water loss from heavy rains, and increasing crop yield and water use efficiency (WUE) in most field crops (Zhang et al., 2007; Li et al., 2013; Qin et al., 2014). In northwest China, crop yields under RFPFM, in comparison with conventional flat planting, have increased by 50%–100%, 30%–90% and 10%–40% in drought, average–rainfall and wetter–than–normal years, respectively (Gan et al., 2013). Increases in the WUE of maize, wheat and potato crops under RFPFM were 30.0%, 53.7% and 63.8%, respectively (Li et al., 2012; Qin et al., 2014; Li et al., 2016).

Therefore, the RFPFM system has become a well–evolved technique that is widely applied in rain–fed semi–arid areas. Many studies have established corresponding theories and adaptabilities for the RFPFM system spreading in arid and semi–arid areas (Gan et al., 2013; Li et al., 2013; Qin et al., 2014). Dry semi–humid areas, defined as zones possessing an annual rainfall of approximately 500–600 mm and a dryness ratio (annual evaporation vs. annual precipitation) of 1.3–1.6, have similar climate conditions to semi–arid areas and often suffer from drought stresses during crop growing seasons, which tend to lower crop yield and productivity. Approximately 15.3 million ha comprise the dry semi–humid region in north China, accounting for 16.1% of the total cultivated area in China with its grain yield accounting for approximately 14.1% of China's grain yield (Wang et al., 2007). Currently, several field studies have been conducted in dry semi–humid areas of northwest China that showed that the RFPFM system could increase crop yields and WUE in these areas (Liu et al., 2010; Zhang et al., 2011; Zhu et al., 2015).

Similarly, our previous study (Li et al., 2016) illustrated that the WUE and crop yield of winter wheat in rotation with summer maize under the RFPFM system were increased by 30.4%–76.1% and 32.2%–88.8%, respectively, when compared with conventional flat planting. To meet the increasing demand for grain, an intensive agricultural system, i.e., a wheat–maize double–cropping system, prevails in our experimental dry semi–humid region. However, the double–cropping system is accompanied by the over–application of N fertilizer and over–consumption of water. It is still unclear whether the RFPFM system could be adapted to this intensive double–cropping system to improve the double–cropping yields and resource use efficiency in a dry semi–humid area of northwest China. The application of nitrogen fertilizer and irrigation water plays a critical role in producing high crop yields in the wheat–maize double–cropping system (Yang et al., 2015; Liu et al., 2016; Zheng et al., 2016). However, the over–use of N fertilization and unreasonable wastage of irrigation water result in a severely lowered resource use efficiency and decreased economic returns, which lead to higher production costs and pollution in soil and underground water sources in terms of sustainable agricultural production (Lybbert and Sumner, 2012; Tang et al., 2015). The objectives of the present study are to (1) compare the summer–maize yield, WUE, and N use efficiency among traditional flat planting, RFPFM, and well irrigation planting under the double–cropping system; and (2) evaluate the feasibility and sustainability of RFPFM practice applied to an intensive winter wheat–summer maize double–cropping system in a dry semi–humid area in northwest China.

2. Materials and methods

2.1. Experiment site description

Field experiments using a winter wheat–summer maize double–cropping system were carried out in 2012–2013 and 2013–2014 at the Sanyuan Experimental Station (34°36′N, 108°52′E; altitude 427.4 m) run by Northwest A&F University in the Shaanxi province of China. The experimental site is located in the Guanzhong Plain and belongs to a typical dry semi–humid area in northwest China (Li et al., 2016). The total crop production area of Guanzhong Plain is 0.67 million ha, most of which is irrigable. The area produces approximately 60% of the total cereal production by taking approximately 45% of the total arable land of Shaanxi province (Li et al., 2016). The winter wheat–summer maize double–cropping system is the dominant cropping system in the Guanzhong Plain. Irrigation was applied two to three times traditionally by local farmers during the summer–maize or winter–wheat growing season when irrigation water was sufficient. The experimental area has a warm temperate, continental

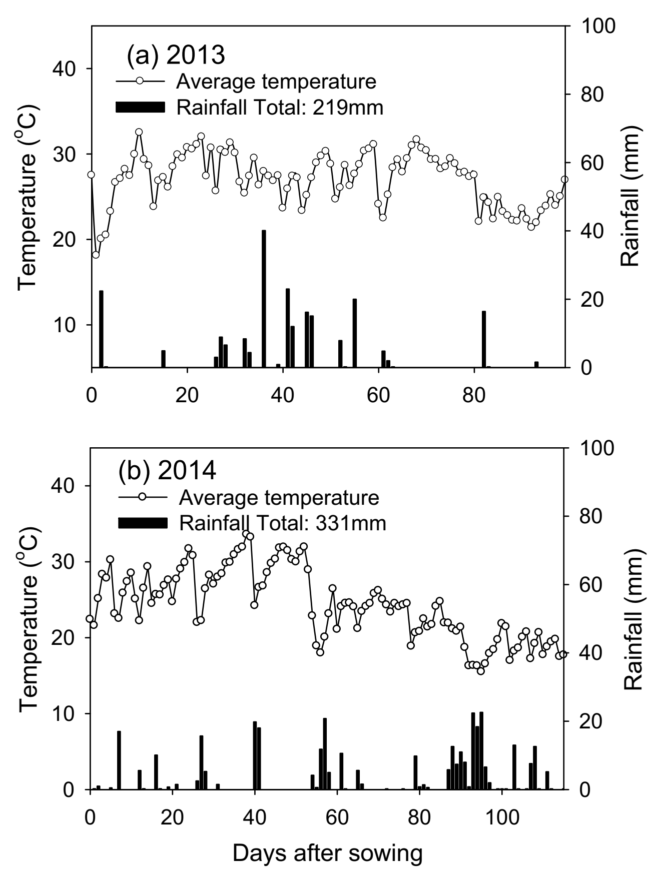

Fig. 1. The daily average air temperature and rainfall during the summer–maize growing season in 2013 and 2014 at Sanyuan Experimental Station, Shaanxi Province, China.