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Towards the highly effective use of precipitation by ridge-furrow with plastic film mulching instead of relying on irrigation resources in a dry semi-humid area

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ABSTRACT

The development of water-saving cultivation techniques has been attracting increased attention worldwide. A rainwater harvesting system known as ridge-furrow with plastic film mulching (RFPFM) has gradually become a promising cultivation method in semiarid rain-fed ecosystems in China. However, it is not well documented, whether this system can be practiced in a semi-humid region where irrigation is available. Field studies comparing three cultivation patterns (rainfed flat planting as CK, RFPFM, and well-irrigated planting pattern: WI) across two different nitrogen (N) rates and two cultivars were conducted for two consecutive years to assess the potential role of RFPFM in improving the water use efficiency (WUE) of winter wheat in a dry semi-humid region of northwest China. The high soil moisture and favourable temperature during the seedling establishing period in the topsoil under RFPFM practice contributed to the emergence of the seedlings 2 days earlier than for CK. Its superiority, also resulted in longer growth duration but also resulting in earlier spikelet and spike differentiation, thereby increasing the grain number per spike, spike number per m^{-2} and wheat yield under RFPFM practice compared with CK. The highest yield of 9.7 t ha^{-1} was achieved in WI combined with a higher N application condition. RFPFM practice resulted in up to approximately 74% of the yield of WI treatment with higher N application, while increasing WUE by 53.7% and 46.3% compared with CK and WI practices, respectively. In addition, RFPFM practice, in comparison with CK, increased the N fertilizer productivity and N uptake efficiency by 52.5% and 44.2%, respectively, averaged across others treatment and years. We highly recommend RFPFM practices with the N rate of 75 kg ha^{-1} as a water-saving technology and a promising strategy to increase wheat yield and WUE in the current agro-ecosystem of northwest China.

1. Introduction

Wheat (*Triticum* spp.) is grown on more land area than any other commercial crop and continues to be the most important food grain source for humans (Bruinsma, 2003). With the decreasing availability of irrigable agricultural land because of degraded land quality and/or water constraints, reaching ever-higher wheat production levels will require the more efficient use of our land and limited water supplies (Deng et al., 2006; Mueller et al., 2012). Producing more wheat with minimum irrigable water is important for the future sustainability of wheat production systems (Mueller et al., 2012; Wu and Ma, 2015).

In recent years, severe scarcity of irrigation water, combined with unpredictable and limited precipitation, which has become more serious with global climate change, has greatly affected agricultural production and productivity (Piao et al., 2010). In some irrigated regions of north China, it is impossible for smallholders to irrigating wheat fields to cope with drought as before (Deng et al., 2006). For instance, some branches of Yellow River have dried up in the winter season for several years, to the extent that water did not flow into the sea (MWR, 2000; Deng et al., 2006). In addition, the groundwater, a primary source of water for irrigation, has become scarce, with the level declining rapidly from approximately 10 m below the ground in the 1970s to approximately 30 m

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in 2001 (Zhang et al., 2003). This decline in the availability of irrigation water could threaten the productivity and sustainability of wheat production in irrigated regions of northwest China. It is promising that some innovative water-saving technologies developed in semi-arid regions might be introduced into semi-humid regions, resulting in the highly effective use of precipitation without much irrigable water input. In this way, irrigation will become less or unnecessary for wheat production in semi-humid areas where water availability is becoming severely insufficient.

Since the early 1990s, several cheaper and more effective technologies, including plastic film mulching and rainwater harvesting strategies, have been widely developed and applied in semiarid agroecosystems (Li et al., 1999; Li and Gong, 2002; Zhou et al., 2015). One innovative water-saving technology, called the ridge-furrow with plastic film mulching (RFPFM) system, has been developed to drastically increase the precipitation use efficiency in rain-fed farming systems in arid and semiarid areas worldwide (Gan et al., 2013; Li et al., 2013; Hu et al., 2014; Wang et al., 2015a). The RFPFM practice, as a rainwater harvesting system, includes two technical components: mulching and ridge furrowing (Zhou et al., 2009). Mulching is typically implemented using plastic film, crop straw, gravel sands, rocks and concrete, which are applied to the field before or shortly after sowing to physically cover the topsoil and preserve the soil moisture (Gan et al., 2013). Ridge furrowing refers to the different widths of ridges that are built in the field, alternating with corresponding furrows. The soil is removed to the ridges from the counterpart furrows to form a topographic superiority to channel rainwater into furrows and minimize surface water runoff (Zhou et al., 2009; Gan et al., 2013). The merits of RFPFM practice are well evidenced in maize, wheat, alfalfa, potato, etc. (Cheng et al., 2012; Hu et al., 2014; Liu et al., 2014a; Wang et al., 2015a).

The RFPFM practice is being rapidly developed and adopted in arid and semi-arid areas where rainfall is low, unpredictable and infrequent and where irrigation is not available and soil temperature is low during the early growth stage of the crops (Li et al., 2013; Liu et al., 2014b). Dry semi-humid areas, which belong to semi-humid areas, have similar meteorological factors to semi-arid areas and always undergo drought stresses during the cropping season, resulting in low crop productivity. Although some excellent research has been conducted on the principles and adaptations of RFPFM practice (Li et al., 1999; Gan et al., 2013), whether RFPFM can be introduced and practiced well in semi-humid areas remains unknown. Therefore, we hypothesize that increasing WUE through RFPFM practice for the highly efficient use of precipitation instead of relying on irrigation resources will play a significant role in maintaining water sustainability and food security in irrigated regions of dry semi-humid areas.

The current experimental site is at the Guanzhong Plain crop production area, possessing 0.67 million ha, which is one of the most important food production areas in northwest China. Most of the Guanzhong Plain is irrigated, and it provides approximately 60% of total cereal production in Shaanxi province, although its area is only approximately 45% of the total harvested area. In this area, unreasonable levels of irrigation and excessive N application have led to severely lowered efficiency of the use of water and N fertilizer, causing higher production costs and severe pollution of the soil and underground water (Deng et al., 2006; Fang et al., 2006; Zhang et al., 2010). The main objectives of this paper are to (i) evaluate the feasibility of RFPFM practice applied to the environment of this irrigated region and (ii) compare the winter wheat yield, water use efficiency and nitrogen (N) use efficiency among the rainfed flat planting, RFPFM and well-irrigated pattern in a dry semi-humid area in northwest China.

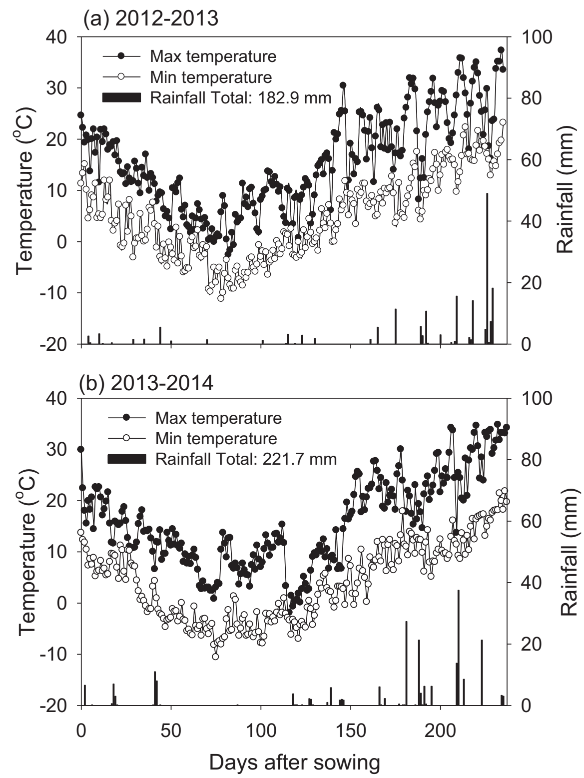

Fig. 1. The daily maximum/minimum temperature and rainfall during the wheat growing seasons in experimental fields at Sanyuan Experimental Station, Shaanxi Province, China in 2012–2013 and 2013–2014.

2. Materials and methods

2.1. Experimental design and cultivation practices

Field experiments were conducted in the 2012–2013 and 2013–2014 growth seasons in the same field at Sanyuan Experimental Station, Shaanxi Province (34°36′N, 108°52′E), which is a typical winter wheat planting area in the Guanzhong Plain. In this region, irrigation is generally implemented fourth in the sowing, tilling, jointing and heading stage if irrigation water is available, according to our recent local survey. The soil properties of the field for both years are shown in Table 1. The annual precipitation level in 2012, 2013 and 2014 were 402 mm, 450 mm and 539 mm, respectively. The daily maximum/minimum temperature and rainfall during the winter wheat growth seasons *in situ*, obtained from a local weather station (Vantage Pro2, USA) installed near the experimental field, are presented in Fig. 1. Precipitation during the crop growth season was 183 and 222 mm in the first and second experimental years.

Treatments were arranged in a split-split plot design with three replications in both years. The main plots were the three planting patterns (CK: rainfed flat planting, RFPFM: ridge-furrow with plastic film mulching, and WI: well-irrigated planting). The schematic performance for RFPFM practice is presented in Fig. 2a. The subplots were two N rates: 75 and 225 kg N ha^{-1}. The sub-sub-plots were two wheat cultivars: Xinong979 and Xiaoyan22. Both cultivars are widely used commercial cultivars with high-yielding potential. Each subplot area was 24 m^2 with a width of 4 m.

To minimize seepage between different planting patterns, the main plots were separated by double bunds (with width of 0.8 m) to prevent water filtering from the WI to the RFPFM and CK plots. For the irrigation management for WI treatment, irrigation of 120,