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Effect of rainfall concentration with different ridge widths on winter wheat production under semiarid climate

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ABSTRACT

Ridge and furrow rainfall concentration (RC) system has gradually been popularized to increase water availability to crops for improving and stabilizing agricultural production in the semiarid area of northwest China. The system is comprised of two elements: the plastic-covered ridge serves as rainfall harvesting zones and the furrow serves as planting zones. To make this system more perfect for alleviating drought stress in semiarid region, it is necessary to test optimum planting systems. A field experiment was conducted from 2007 to 2010 to evaluate the effects of RC planting on soil moisture, wheat yield and water use efficiency (*WUE*) under different ridge widths. Four planting systems were designed (RC_{40}: 40 cm ridge with 60 cm furrow width, RC_{60}: 60 cm ridge with 60 cm furrow width, RC_{80}: 80 cm ridge with 60 cm furrow width, and CF: conventional flat without ridging). The results showed that RC planting can significantly increase soil moisture in 0–200 cm during the growing seasons of winter wheat. The rainfall-harvesting effect increased with ridge width increasing. Winter wheat yield and WUE was significantly higher under RC_{60} than under CF by 405.1 kg ha^{-1} and 2.39 kg mm^{-1} ha^{-1}, respectively, on average across the three experimental years ($P < 0.05$). The above findings indicate that RC_{60} can benefit winter wheat cropping for higher yield through improving soil moisture. It could be concluded that the RC planting system with 60 cm ridge and furrow width will offer a sound opportunity for sustainable farming in semiarid dryland agricultural area.

1. Introduction

The Loess Plateau of northwest China is one of the most important regions of agricultural production in China. The region covers an area of 624,000 km^2. However, precipitations are relatively rare in these areas with an average annual amount of only about 450 mm, with 70% of rainfall falling between July and September (Li, 2000), As a result, droughts are a common occurrence and water is becoming main limiting factors during crop growing seasons. This presents a serious environmental problem for sustainable agricultural development in the region. To cope with the water shortage problem, it is necessary to adopt water-saving agriculture countermeasures to achieve the largest possible increase in water use efficiency (*WUE*) of crops (Yao and Yin, 1999; Li et al., 2001a).

Rainwater concentration (RC) planting has been used for many years in semiarid areas to solve problems of domestic and irrigation water shortages (Ren et al., 2010a,b). Based on the idea of spot rain harvesting and utilization, the ridge and furrow water-harvesting planting (also called root zone water-harvesting planting) is a type of micro-rain-harvesting system. The method developed in the Loess Plateau of northwest China which has been adopted prevalently in the dryland farming (Zhang et al., 2007). In this system, the plastic-covered ridge serves as rainfall harvesting zones and the furrow serves as planting zones. The interrelationships and interactions among ridges and furrows regulate the water environment required for crop growth. This is crucial for improving crop production potential with limited precipitation (Ren et al., 2008). The results of many studies have indicated that this system can harvest the surface runoff, reduce ineffective evaporation, increase soil moisture, and improve the productivity of crops (Li et al., 2000, 2001b; Wang et al., 2005; Tian et al., 2003; Jia et al., 2006; Li and Gao, 2004). Li and Zhang (2005) reported that adopting RC system could significantly improve topsoil temperature and moisture, and make seedlings emerge earlier. Wang et al. (2004) also indicated

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that the combination of RC and mulches could increase crop WUE and biological yields, and reduce costs.

Winter wheat (*Triticum aestivum* L.) is a major food crop in the semiarid dryland farming areas of the Loess Plateau in China. The increase of wheat yield in this region depends greatly on the field soil moisture storage. However, winter wheat is sown each year at the end of September or the beginning of October and harvested at the end of June or the beginning of July in the following year. The annual growth of winter wheat is characterized by relatively low precipitation and this temporal mismatch between growing season and precipitation distribution leads directly to severe water shortages and yield decrease. In order to ensure higher yield, the plastic-covered ridge and furrow RC system has been promoted widely in semiarid areas. In past decades, the technology was mainly used for crops with relatively small row distances and large planting densities, such as corn and potato. Although remarkable yield-increasing effects can be obtained, the rain-harvesting ridges in this system will occupy part of the cultivation area. Then whether can the yield increases achieved by improving water conditions offset the losses caused by a reduced cultivation area, and the yield-increasing effect be related to variety of crop types? The answer to this question will be essential for the widespread adoption of RC planting in semiarid areas. However, little is known about effects of rainfall concentration plant on winter wheat soil moisture and yield under different ridge widths during the whole wheat growth period. Effects of RC with different ridge width on soil conditions and wheat growth are still unclear in Northwest China. Therefore, we conducted a field experiment with four planting systems (RC_{40}, RC_{60}, RC_{80} and CF). The purpose of this study is: (1) to investigate the effect of RC planting with different ridge width on winter wheat grain yield and WUE, (2) to investigate the effect of RC planting with different ridge width on soil moisture in various soil layers, and (3) to compare the performance of RC_{40}, RC_{60}, RC_{80} and CF and establish the optimum ridge and furrow width in semiarid dryland farming area.

2. Materials and methods

2.1. Study site description

A field experiment was conducted from September, 2007 to June, 2010 at the Steep Slope Station run by Northwest A&F University (35°79′N, 106°45′E, and 1800 m asl). The station is located in Baiyang Town, Pengyang County, Ningxia Hui Autonomous Area, China, which belongs to the hilly areas of the loess plateau characterized by a temperate semiarid continental monsoon climate. The annual average temperature and sunshine duration are 6.1 °C and 2518.2 h, respectively. Average pan evaporation is 1750 mm and the no frost period is 155 days. Annual precipitation is 435.0 mm with almost 70% occurring in July to September (Fig. 1). According to the annual average precipitation records for the last four decades (1970–2010), there were water deficits in 2007, 2008, and 2009, when the annual precipitation were 82.3 mm, 52.6 mm, and 106.8 mm less than the annual precipitation (435.0 mm), respectively. By contrast, 2010 was a year of water abundance and the annual precipitation was 102.0 mm greater than the average annual rainfall. Between October, 2007 and June, 2010, the precipitation during the winter wheat growing season (early October to late June in the following year) were 157.1 mm, 125.4 mm, and 238.4 mm, respectively, whereas during the summer fallow period (early July to late September), the total precipitation were 275.6 mm, 198.2 mm, and 294.9 mm, respectively (Table 1). The soil in the top 1.2 m is classified as Eum-Orthrosols in Chinese classification. The field experiment was flat grounds of loessal soils with relatively low fertilities. The mean soil bulk density was 1.37 g cm^{-3}. The average field capacity and permanent wilting point of the root zone soil in the crop field were 20 and 6%, respectively. The readily available N, P and K were 46.12, 13.74 and 120.37 mg kg^{-1}, respectively. The organic matter content of 0–20 cm topsoil and pH were 7.36 g kg^{-1} and 8.19, respectively. Prior to the experiment, in 2006, the site was planted to spring corn with about 360 fallow days before winter wheat was sown in September, 2007.

Table 1
Antecedent moisture content at the 0–200 cm soil depth prior to the experiments.

Soil depth (cm)	20	40	60	80	100	120	140	160	180	200
Soil moisture (%)	14.3	9.9	11.2	12.8	14.2	15.1	15.5	15.0	15.5	14.4

2.2. Experiment design and treatments

The experiment comprised four systems: RC_{40}: 40 cm ridge with 60 cm furrow width, RC_{60}: 60 cm ridge with 60 cm furrow width, RC_{80}: 80 cm ridge with 60 cm furrow width, and CF: conventional flat without ridging. The experiment adopted a randomized complete block design with three replications. All treatments, except the CF, had the ridges covered with 0.08 mm thick plastic film. Field experiment was implemented through the adoption of the plastic-covered ridge and furrow rainfall concentration (RC) system. In this system, the ridges (40 cm, 60 cm and 80 cm wide with 75%, 50% and 37.5% slope, respectively) served as rainfall harvesting zone and furrows (60 cm wide) as planting zones. The RC_{40}, RC_{60} and RC_{80} systems consisted of alternating south-north-oriented ridges and furrows, and the height of ridges (or the depth of the furrows) was 15 cm. In field tests, the area of each planting catchment was 10 m × 10 m and the runoff-generating (ridge) areas with a ratio of ridge width to furrow width of 2:3, 1:1 and 4:3 were 10 m × 0.4 m, 10 m × 0.6 m and 10 × 0.8 m, respectively. A schematic diagram of the system with crop configuration is indicated in Fig. 2. The CF had a row spacing of 20 cm, which was the most popular practice used by farmers. Four rows of winter wheat were planted in the furrows with a row spacing of 20 cm under RC treatments. Seedling density of 110 plants m^{-1} was used for all the four systems. The effects of RC were calculated based on the total areas of the ridges and furrows. Winter wheat (using "Xifeng no. 27" as index crop) was planted on 20 September, 2007, 2008 and 2009, respectively, and harvested on 25 June, 2008, 2009 and 2010, respectively. The side rows of every catchment served as protective rows. Plastic films functioning as water isolation belts were buried with a depth of 2 m at the edges of each catchment, so as to prevent water inter-infiltration among these catchments.

At 30 days before sowing, the ridges were banked up with soil on the spot and covered with plastic film (PE film, 1.0 m wide and 0.008 mm thick), and then the planting belts or furrows were leveled. Organic matter and fertilizer was applied to the furrows at a rate of 37,500 kg yard manure ha^{-1}, 150 kg N ha^{-1}, 150 kg P_2O_5 ha^{-1} and 150 kg K_2O ha^{-1}. The fertilizer was applied in furrows for the ridge and furrow plots. In each RC plot, the sowing rate and fertility application rate were at the same levels with those of CF plots based on the land areas. Although the sowing rate and nitrogen application rate in each row of RC were twice as those of CF, they were the same on the basis of total plot area including ridge and furrow. Sowing in drills was implemented at a depth of about 5 cm. After the over-wintering stage, a pure nitrogen topdressing was applied at a rate of 150 kg ha^{-1}, but no further topdressing or irrigation were applied. During the entire winter wheat growing season, weed and pest control was performed as necessary.