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RESEARCH ARTICLE

Ridge-furrow rainwater harvesting with supplemental irrigation to improve seed yield and water use efficiency of winter oilseed rape (*Brassica napus* L.)

GU Xiao-bo, LI Yuan-nong, DU Ya-dan, YIN Min-hua

College of Water Resources and Architectural Engineering, Northwest A&F University/Key Laboratory of Agricultural Soil and Water Engineering in Arid and Semiarid Area, Ministry of Education, Yangling 712100, P.R.China

Abstract

Ridge-furrow rainwater harvesting (RFRH) planting pattern can lessen the effect of water deficits throughout all crop growth stages, but water shortage would remain unavoidable during some stages of crop growth in arid and semiarid areas. Supplemental irrigation would still be needed to achieve a higher production. Field experiments were conducted for two growing seasons (2012–2013 and 2013–2014) to determine an appropriate amount of supplemental irrigation to be applied to winter oilseed rape at the stem-elongation stage with RFRH planting pattern. Four treatments, including supplemental irrigation amount of 0 (I1), 60 mm (I2) and 120 mm (I3) with RFRH planting pattern and a control (CK) irrigated with 120 mm with flat planting pattern, were set up to evaluate the effects of supplemental irrigation on aboveground dry matter (ADM), nitrogen nutrition index (NNI), radiation use efficiency (RUE), water use efficiency (WUE), and seed yield and oil content of the oilseed rape. Results showed that supplemental irrigation improved NNI, RUE, seed yield and oil content, and WUE. However, the NNI, RUE, seed yield and oil content, and WUE did not increase significantly or even showed a downward trend with excessive irrigation. Seed yield was the highest in I3 for both growing seasons. Seed yield and WUE in I3 averaged 3235 kg ha^{-1} and 8.85 kg ha^{-1} mm^{-1}, respectively. The highest WUE was occurred in I2 for both growing seasons. Seed yield and WUE in I2 averaged 3089 kg ha^{-1} and 9.63 kg ha^{-1} mm^{-1}, respectively. Compared to I3, I2 used 60 mm less irrigation amount, had an 8.9% higher WUE, but only 4.5 and 0.4% lower seed yield and oil content, respectively. I2 saved water without substantially sacrificing yield or oil content, so it is recommended as an appropriate cultivation and irrigation schedule for winter oilseed rape at the stem-elongation stage.

Keywords: ridge-furrow rainwater harvesting (RFRH), supplemental irrigation, winter oilseed rape, seed yield, oil content, water use efficience (WUE)

1. Introduction

Northwestern China contains about 55% of the total national arable land, but has <20% of the total water resources (Deng *et al.* 2006) and lower rainfall due to the warming climate and persistent droughts (Wei and Ba 2003). Water scarcity has become the most critical restriction to the sustainable

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GU Xiao-bo, E-mail: gxb123027@163.com; Correspondence LI Yuan-nong, E-mail: liyuannong@163.com

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development of agriculture in northwestern China (Dang *et al.* 2006). Water-saving methods must therefore be adopted to improve agricultural productivity and water use efficiency (WUE) in this region (Shao *et al.* 2007).

Ridge-furrow rainwater harvesting (RFRH) planting pattern, with ridges mulched with plastic film that serve as the runoff area and with furrows as the infiltration or planting area, has been a useful method for improving crop productivity in arid and semi-arid areas (Boers *et al.* 1986; Tian *et al.* 2003). The RFRH planting pattern can significantly improve soil-water availability, crop yield, and WUE (Oweis and Hachum 2006; Ren *et al.* 2008; Wang *et al.* 2008). Li *et al.* (2000) reported an efficiency of harvesting rainwater of about 87% under the RFRH planting pattern due to the better use of light rainfalls <5 mm. Previous studies have mainly evaluated the effects of the RFRH planting pattern on crops such as maize (Wang *et al.* 2009), wheat (Zhang *et al.* 2007), oats (Qiang *et al.* 2011), potato (Qin *et al.* 2014), and alfalfa (Li *et al.* 2007). The effect on winter oilseed rape (*Brassica napus* L.), however, has not been reported.

Oilseed rape is one of the most important oil crops in China, with about 7.5 million ha cultivated and 14.4 million tonnes of seeds produced in 2013 (FAO 2016). Winter oilseed rape in China is mainly cultivated in the Yangtze River Basin, but with rising winter temperatures in northern China in recent years, its planting area in the northwestern China has increased year by year (Yin *et al.* 2010; Zhang and Wang 2012). Yields, however, have always been low and unstable due to poor WUE from extensive cultivation and irrigation method (Jing and Dong 2004).

The effect of water shortage throughout all stages of crop growth can be lessened by the RFRH planting pattern, but water deficits would remain unavoidable during some crop growing stages due to the uneven distribution of rainfall (Kang *et al.* 2002; Pan *et al.* 2003). Thus, supplemental irrigation would be needed to achieve higher production (Xiao *et al.* 2005). The stem-elongation stage is a critical period for oilseed rape for building the branching structure and strong stems, then producing high yields. But the frequency of drought during this stage is high in northwestern China, and rainfall alone cannot satisfy the needs of the crops. Local farmers have long adopted flood irrigation to achieve high benefits, but with no obvious effect (Gu *et al.* 2015).

Radiation use efficiency (RUE) and the nitrogen nutrition index (NNI) are two helpful indicators for understanding crop growth and yield (Diepenbrock 2000; Lemaire *et al.* 2008). The RUE and NNI of crops under the RFRH planting pattern, however, have not been assessed. The objectives of this study were thus to: (1) evaluate the effects of the irrigation amount on the RUE, NNI and ET under RFRH planting pattern, and (2) determine an appropriate amount of irrigation at the stem-elongation stage to maximise WUE and seed yield for winter oilseed rape in northwestern China.

2. Materials and methods

2.1. Experimental site

Field experiments were conducted at the Key Laboratory of Agricultural Soil and Water Engineering in Arid and Semiarid Areas of the Ministry of Education (34°18´N, 108°24´E; 521 m a.s.l.), Northwest A&F University, Yangling, Shaanxi, China, from September 2012 to May 2014. The mean annual precipitation of the study area is about 632 mm, with a pan evaporation of 1 500 mm, mean annual temperature of 12.9°C, mean annual sunshine duration of 2 163.8 h, and a mean annual frost-free period of more than 210 d. The water table is deeper than 8 m. The soil of the experimental field is a medium loam with a field capacity of 24.0% and dry bulk density of 1.40 g cm^{-3}. The nutrient properties of the top soil layer (0–20 cm) at the start of the experiments are shown in Table 1.

Total rainfall during the growing period at the experimental site was 371.6, 120, and 330 mm for 2006–2011, 2012–2013, and 2013–2014, respectively (Fig. 1-A). The monthly total rainfall for 2006–2011 was the mean value of the corresponding month in the five growing seasons. Monthly mean temperatures during the two growing seasons followed a similar trend and were similar to the monthly mean temperatures for 2006–2011, except for a significantly lower mean January temperature for 2006–2011 (Fig. 1-B). Rainfall from March to May was much higher for 2013–2014 (197 mm) than for 2012–2013 (52 mm). The rapeseed crops in 2012–2013 were thus affected by a severe drought.

2.2. Experimental design

Four treatments were arranged in a completely randomised design with three replicates in the two growing seasons: a control treatment (CK) with flat planting pattern and irrigated with 120 mm and three treatments with RFRH planting pattern and receiving 0 (I1), 60 mm (I2), and 120 mm (I3) of supplemental

Table 1 Soil nutrient properties (0–20 cm) at the start of the 2012–2013 and 2013–2014 growing seasons

Growing season	pH (water)	Organic matter (g kg^{-1})	Total N (g kg^{-1})	Nitrate N (mg kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})
2012–2013	8.13	13.36	0.96	73.01	24.07	135.73
2013–2014	8.14	12.78	0.98	72.54	24.26	135.32