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Effects of ridge-furrow film mulching and nitrogen fertilization on growth, seed yield and water productivity of winter oilseed rape (*Brassica napus* L.) in Northwestern China

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ABSTRACT

Poor soil conditions and drought stress are two main factors restricting the agriculture production in arid and semiarid areas of China. The ridge-furrow film mulching (RFFM) cultivation pattern has been shown to have the ability of improving yield and water productivity (WP) of maize, wheat and potato. However, its effect on winter oilseed rape is not clear. A two-year (2014–2016) field experiment was conducted to determine whether the RFFM cultivation pattern has the potential of improving winter oilseed rape productivity under dryland conditions. The optimal nitrogen (N) application rate for winter oilseed rape maximum yield under the RFFM cultivation pattern was also measured. Winter oilseed rape was planted in RFFM and flat cultivation patterns, both with six nitrogen (N) application rates (0, 60, 120, 180, 240 and 300 kg ha^{-1}). The results showed that compared to the flat cultivation pattern, the RFFM cultivation pattern greatly increased leaf area index (LAI) by 18.7% on average, aboveground dry matter (ADM) by 25.6% at harvest, seed yield by 23.8% and WP by 32.7%, and decreased evapotranspiration (ET) by 7.2%. Application of N fertilizer remarkably increased LAI, ADM, ET, seed yield and WP of winter oilseed rape under both cultivation patterns. Under the RFFM cultivation pattern, average seed yield, WP, and economic benefit in 240 kg N ha^{-1} were 2904 kg ha^{-1}, 8.8 kg ha^{-1} mm^{-1}, and 1259.6 $ ha^{-1}, respectively, and were significantly higher than the other five N rates. The optimal N-application amount for maximum winter oilseed rape productivity under the RFFM cultivation pattern was found to be 240 kg N ha^{-1}. In conclusion, the RFFM cultivation pattern has the potential of improving the seed yield and WP of winter oilseed rape in northwest China.

1. Introduction

Droughts majorly limit crop production in arid and semiarid regions of northwest China (Huang et al., 2005; Wang et al., 2009; Zhang et al., 2009). Low yields have been reported in spring wheat (about 1500–3000 kg ha^{-1}) and maize (2500–3500 kg ha^{-1}) crops in areas where heat leads to high evaporation and rainfall is sparse and unevenly distributed (Hu et al., 2009; Huang et al., 2005; Wang et al., 2008). Film mulching is an important agricultural technique for improving soil moisture and crop yields (Gan et al., 2013). The ridge-furrow planting pattern has also been widely applied to conserve soil water during crop production (Li et al., 2007). The combination of the two techniques has been termed the ridge-furrow film mulching (RFFM) planting pattern, which employs ridges mulched with plastic film to serve as the runoff area and furrows used as the planting area (Li et al., 2001; Li and Gong, 2002). Numerous studies have demonstrated that the RFFM planting pattern significantly improves soil water availability, crop yield, and water productivity (WP) in maize (Wang et al., 2009; Wang et al., 2015), wheat (Li et al., 2017; Zhang et al., 2007), and potato (Qin et al., 2014; Zhao et al., 2012). However, the RFFM planting pattern has rarely been tested in oilseed rape (*Brassica napus* L.) for yield improvements in areas where soil evaporation is high.

Oilseed rape is one of the most widely cultivated oil crops throughout the world. As one of the leading rapeseed producing countries, China generated an annual average of 12.6 million tons of seeds from 2001 to 2014 (FAOSTAT, 2016). Chinese rapeseed

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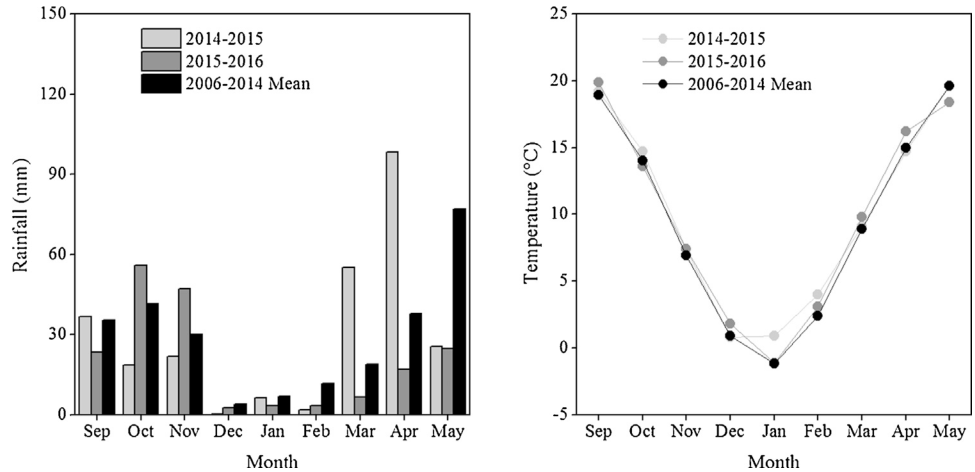

Fig 1. Monthly total rainfall and monthly mean temperature during the winter oilseed rape season in 2014–2015, 2015–2016, and 2006–2014 (mean value) at the experimental site.

yields have steadily increased over the last five decades not only due to the introduction of high-yield potential cultivars and the improved agronomic practices, but also the higher nitrogen-based fertilizer inputs (Hamzei and Soltani, 2012; Rathke et al., 2006). However, excessive use of N fertilizers not only causes a huge waste of resources and economic losses, but also adversely impacts the environment (Godfray et al., 2010), thereby affecting the safety of human beings (Hvistendahl, 2010).

Oilseed rape response to N fertilizers is dependent upon many environmental factors including water availability, ambient temperature and soil properties (Rathke et al., 2006). RFFM planting pattern has been suggested to have an effect on soil N-transport, N mineralization and plant N uptake through its effect on soil temperature and moisture (Wang et al., 2015). All of these factors may alter the responses of oilseed rape to N fertilization, affecting seed yield. The objectives of the present study were to examine the coupling effects of the RFFM planting pattern and N fertilizer on leaf area index, aboveground dry matter, evapotranspiration, seed yield and WP of winter oilseed rape. Results from this study may provide information that can be used to (1) determine whether the RFFM planting pattern has the potential to improve winter oilseed rape productivity and (2) offer insight into optimum N application rates under the RFFM system for high oilseed rape yields and WP.

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 at the Ministry of Education (34°18\N, 108°24\E, 521 m ASL), Northwest A&F University, Yangling, Shaanxi, China from September 2014 to May 2016. The average annual precipitation and pan evaporation were approximately 632 mm and 1500 mm, respectively. The mean temperature was 12.9 °C, the duration of sunlight was 2164 h, and the frost-free period was more than 210 d. The experimental field soil was a loam with a field capacity of 24.0%, dry bulk density of 1.40 g cm^{-3}. The nutrient properties of the 0–20 cm soil layer were as follows: soil organic matter 12.18 g kg^{-1}, nitrate nitrogen 76.01 mg kg^{-1}, Olsen phosphorus 25.22 mg kg^{-1}, NH_4OAc-extracted potassium 132.97 mg kg^{-1}, pH (water) 8.14 at the beginning of 2014–2015; and the corresponding data were 12.57 g kg^{-1}, 73.93 mg kg^{-1}, 24.80 mg kg^{-1}, 133.62 mg kg^{-1}, and 8.13, respectively, at the beginning of 2015–2016.

Monthly mean temperatures during the two experimental seasons followed a similar trend and were close to the mean value of 2006–2014, while the temperature in January 2015 was higher than the mean value of 2006–2014 (Fig. 1). Total rainfall during the growing period was 264.3 mm and 183.9 mm for 2014–2015 and 2015–2016, respectively, and the mean rainfall during the growing period in 2006–2014 was about 263 mm at the experimental site. March to May is the stem elongation, flowering, and pod-filling stages of winter oilseed rape occurring in northwest China. Rainfall from March to May in 2014–2015 and 2015–2016 was 178.7 and 48.1 mm, which was 33.4% more and 64.1% lower than the mean value of 2006–2014 (134 mm), respectively.

2.2. Experimental design

Field experiments for each season were arranged on a split plot design with the cultivation pattern as the main plot and the N levels as the subplot. Each plot was 20 m^2 (4 m × 5 m) in size and three replicates were conducted in each season. Two cultivation patterns were involved in the experiment: ridge-furrow film mulching (Fig. 2a) and flat planting (Fig. 2b) methods. Each cultivation pattern had six N levels: 0 (N0), 60 (N60), 120 (N120), 180 (N180), 240 (N240) and 300 (N300) kg N ha^{-1}, in the form of urea (N = 46%) and were all applied as basal fertilizer. In addition, calcium superphosphate (P_2O_5 = 16%), potassium sulphate (K_2O = 51%), and borax (B = 11%) were applied at rates of 90 kg P_2O_5 ha^{-1}, 120 kg K_2O ha^{-1}, and 15 kg B ha^{-1} in each plot before oilseed rape was sown. No additional fertilizer was applied during the growth of the oilseed rape.

After ploughing and leveling the experimental field, dividing the experimental plots, and applying all basal fertilizers in each plot, the ridges and furrows as shown in Fig. 2a were formed. Seeds of winter rape 'Shaanyou No. 107' were manually sown on 21 September 2014, and 16 September 2015. Transparent plastic film, 0.8 m wide and 0.008 mm thick, was laid over the soil surface layer of ridges immediately after emergence for the RFFM treatments (Fig. 2a). Plant density was determined as 120 000 plants ha^{-1} at the fifth-leaf stage by manually thinning seedlings. Other field production practices such as weed and pest control were conducted to minimise yield loss. The plastic film was gathered and recycled after the crop was harvested on 23 May 2015, and 20 May 2016. No irrigation was applied during the growth of winter oilseed rape for both seasons.