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Interactive effects of plastic film mulching with supplemental irrigation on winter wheat photosynthesis, chlorophyll fluorescence and yield under simulated precipitation conditions

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ABSTRACT

Water shortages continuously threaten agricultural productivity in semi-arid regions. Efficient water-saving management practices urgently need to be developed. In the present study, a mobile rain shelter was used with two cultivation modes: (1) the ridge furrow (R) rainfall harvesting system; and (2) traditional flat planting (F). In addition, two supplemental irrigation levels (150, 75 mm) and three precipitation levels (1: 275, 2: 200, 3: 125 mm) were included in this study. We demonstrated that the R system with 150 mm supplemental irrigation and 200 mm simulated rainfall can significantly improve winter wheat net photosynthesis rate (Pn), electron transport rate (ETR), effective quantum yield of PS II (Φ_{psII}), maximum quantum efficiency of PSII (Fv/Fm), variable fluorescence (Fv), energy transformation potential of PSII (Fv/Fo), and leaf photosynthetic performance index of PSII (Fv/Fm′), at the jointing, flowering, and later stage of grain filling. These improvements were due to significantly increased soil moisture content, total chlorophyll ab contents (13.1%), and chlorophyll stability index (88.3%) of flag leaves, and decreased (32.7%) evapotranspiration (ET) at field scales and soil temperature, all of which increased the grain yield (18.9%) and water use efficiency (WUE, 75.8%) compared with traditional flat planting. The chlorophyll fluorescence parameters of winter wheat were significantly positively correlated with the Pn, total Chl, WUE, and grain yield (except ET). These results suggest that the R system with 150 mm supplemental irrigation and 200 mm simulated rainfall was the best cultivation practice for improving photosynthesis, chlorophyll fluorescence, WUE, and yield of winter wheat in semi-arid regions.

1. Introduction

Winter wheat is one of the most important crops in the semi-arid regions of China and more than 60% of wheat grown in China is grown there. However, minimal precipitation and uneven rainfall distributions are major factors affecting production and water use efficiency (WUE) in these regions (de Santana et al., 2015), and the only practice to maintain sustainable crop productivity is efficient use of irrigation water (Richards, 2000; Kang et al., 2002). Therefore, effective water-saving agricultural technologies urgently need to be developed to maintain high productivity and enhance WUE (Sun et al., 2011). Precipitation is one of the key water resources in semi-arid regions (Han et al., 2004), and uneven or insufficient precipitation have major negative effects on crop production. Therefore, it is important to efficiently use light rainfall and increase soil water storage (Liao et al., 2003).

The ridge furrow (R) precipitation harvesting system with plastic film mulching has been commonly implemented in semi-arid regions to preserve rainwater in the root zone of crops (Wang et al., 2008). Ridges covered with plastic film mulching and limited irrigation have been studied as an extremely effective strategy with great potential for decreasing soil evaporation, and enhancing soil water storage as well as crop growth and yield, and WUE (Oweis and Hachum, 2006;Zhang et al., 2000). However, most of the studies focused on fixed amounts of

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irrigation and did not consider the effect of crop cultivation techniques on the irrigation amount, water consumption, and crop production. Therefore, studies that focus on cultivation techniques and use supplemental irrigation and simulated rainfall are needed in order to develop effective water-saving agricultural in semi-arid regions.

Photosynthesis and chlorophyll fluorescence are the physiological processes that are most sensitive to water stress (Pan et al., 2014). Several studies indicated that soil water content significantly affected photosynthesis and chlorophyll fluorescence parameters and wheat production (Yang et al., 2000; Luo et al., 2011). It is generally recognized that increasing soil water content through micro rainwater collection methods can help increase CO_2 diffusion from the atmosphere to the site of carboxylation due to stomatal opening and increased mesophyll conductance, which, in turn, contributes to an increase in net photosynthetic rate, and the content, stability index, and fluorescence of chlorophyll (Ashraf and Harris, 2013; Chaves and Oliveira, 2004). Previous studies reported that water scarcity that occurs during flowering and grain filling stages can inhibit and reduce the period of photosynthesis and significantly increase flag leaf senescence, which may reduce the contribution of pre-flowering assimilates to grains (Xue et al., 2006; Wu et al., 2014). The R system with supplemental irrigation could improve the stomatal regulation of plants, and also sustain the physiological function of the photosynthetic apparatus by increasing chlorophyll content and fluorescence (DaMatta et al., 2002).

Chlorophyll fluorescence, an important component of plant photosynthesis, can be used as an indicator to evaluate yield performance, and it is sensitive to water deficit (Zivcak et al., 2013; Xu et al., 2014). Fluorescence measurements could be widely used to study photosynthetic performance in leaves, and they can provide useful information on physical changes in pigment protein complexes and the electron transport rate through PSII (Govindjee, 2004; Baker & Rosenqvist, 2004). Water stress not only causes structural damage to PSII but can also affect the process of photosynthetic electron transport, maximum photochemical efficiency (Fv/Fm), and actual photochemical efficiency (Φ_{PSII}) of PSII (Tambussi et al., 2005; Hura et al., 2007). Photosynthetic activities of plants are improved under micro rainwater harvesting with plastic film mulching compared to conventional flat planting with plastic film mulching (Hossain et al., 2011). However, knowledge of how winter wheat photosynthesis, fluorescence, and production are affected by different cultivation modes with supplemental irrigation under simulated rainfall conditions is relatively limited. Thus, the main objective of the study was to determine whether photosynthesis, chlorophyll content and fluorescence, and production of wheat are affected by cultivation modes with supplemental irrigation under simulated rainfall conditions. We believe that the results can be used to explore the interactive effect of cultivation modes with supplemental irrigation under simulated rainfall conditions and provide a scientific basis for improving winter wheat production in semi-arid regions.

2. Materials and methods

2.1. Study site description

The field study was performed during 2015–2017 at the Northwest A&F University, Shaanxi Province, China (34°20′N, 108°24′E). The experimental site was 466.7 m above sea level; annual mean temperature is 12.9 °C, with a frost-free period of 220 days per year (Fig. 1). The mean soil bulk density was 1.37 g cm^{-3}. The averages of two years of available NPK data were 39.4 mg kg^{-1}, 7.98 mg kg^{-1} and 99.94 mg kg^{-1}. At the 0–20 cm soil layer, the soil organic matter was 10.88 g kg^{-1} and the pH was 7.80.

2.2. Experimental design and treatments

The research trial consisted of two cultivation models (1) the ridge furrow precipitation harvesting technique (R); and (2) flat cultivation technique (F), under two supplemental irrigation (150, 75 mm) levels and three rainfall (1: 275, 2: 200, 3: 125 mm) levels in a randomized complete block design (RCBD) with four replicate. The field study was performed under waterproof sheds. The size inside the shed was 3 m (height) × 15 m (width) × 32 m (length). The mobile waterproof sheds were used to manage natural rainfall. In this study, simulated rainfall was used according to methods in our previous study (Ali et al., 2017) and no natural precipitation was allowed during the wheat growing season. Complete detail about the precipitation conditions can be seen in (Table 1). The amount of rainwater used for this study was reasonably similar to natural rainfall amounts of semi-arid regions. Using a precise water meter, half of the supplemental irrigation was supplied on December 12, 2015 and December 15, 2016 (before the re-wintering stage) and the other half was supplied on March 28, 2016 and March 25, 2017 at the jointing stage. The supplemental irrigation volumes for 150 and 75 mm were measured according to the irrigation area. The irrigation area in the F cultivation treatment was 6.3 m^2 (2.0 m × 3.15 m), and the irrigation volume was 0.95 and 0.47 m^3 under 150 and 75 mm, respectively. The irrigation area under the R technique of the two furrows was 3.78 m^2 (1.2 m × 3.15 m), and the irrigation volumes of the two furrows were 0.57 and 0.28 m^3. The R technique used a ridge height of 15 cm with a ratio of the furrow to ridge widths of 60:40 cm. A plastic film was used to cover all ridges

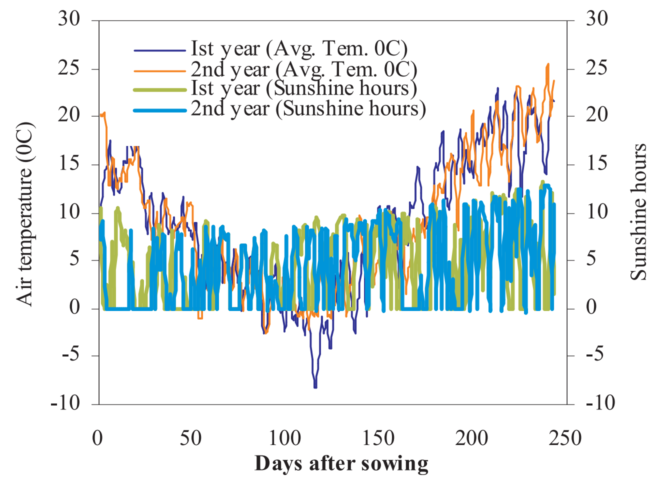

Fig. 1. The daily average air temperature and total sunshine hours during the winter wheat growing seasons in experimental fields at Northwest A&F University, Yangling, Shaanxi Province, China in 2015–2016 and 2016–2017.

Table 1
Partition of rainfall simulation during winter wheat-growing seasons.

Growth stages	Rainfall events	Rainfall duration	Daily rainfall distribution (mm)		
			125 mm	200 mm	275 mm
Seedling	2	28–29 October	25	32	40
		24–25 November	13	22	30
Wintering	2	18–19 December	4	5	4
		22–23 January	3	5	6
Green	1	26–27 February	5	10	12
Jointing	1	20–21 March	15	24	43
Grain filling	3	9–10 April	15	30	25
		26–27 April	15	22	25
		10–11 May	15	25	45
Maturing	1	23–24 May	15	25	45