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RESEARCH ARTICLE

Contribution of ear photosynthesis to grain yield under rainfed and irrigation conditions for winter wheat cultivars released in the past 30 years in North China Plain

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Abstract

To understand the contribution of ear photosynthesis to grain yield and its response to water supply in the improvement of winter wheat, 15 cultivars released from 1980 to 2012 in North China Plain (NCP) were planted under rainfed and irrigated conditions from 2011 to 2013, and the ear photosynthesis was tested by ear shading. During the past 30 years, grain yield significantly increased, the flag leaf area slightly increased under irrigated condition but decreased significantly under rain-fed condition, the ratio of grain weight:leaf area significantly increased, and the contribution of ear photosynthesis to grain yield changed from 33.6 to 64.5% and from 32.2 to 57.2% under rainfed and irrigated conditions, respectively. Grain yield, yield components, and ratio of grain weight:leaf area were positively related with contribution of ear photosynthesis. The increase in grain yield in winter wheat was related with improvement in ear photosynthesis contribution in NCP, especially under rainfed condition.

Keywords: wheat, ear photosynthesis, grain yield, improvement of cultivars

1. Introduction

Wheat is the third leading crop in China after rice and maize (Zheng *et al.* 2011). The rising Chinese population and the rapid growth of the economy have resulted in an increasing demand for wheat (*Triticum aestivum* L.) in the following decades (Zhou *et al.* 2013). The planting area in China is shrinking (Zhang *et al.* 2008; Zhou *et al.* 2013; Xue *et al.* 2014). Therefore, it is necessary to further increase yield per unit area of wheat. Water shortage is a serious issue threatening the sustainable development of agriculture in North China Plain (NCP) (Zheng *et al.* 2014). The rainfall during winter wheat growth can only meet 25–40% of requirement, leading to a deficit for 200–300 mm water in the northern part of the NCP (Liu *et al.* 2001; Zhang *et al.* 2006; Liu *et al.* 2013), due to the summer monsoon climate and climate change (Piao *et al.* 2010). Hence, an irrigation of more than 400 mm water was applied, carried out 3–4 times per season, achieving high grain yield of wheat (Zhang *et al.* 2003). However, overdraft of groundwater has resulted in a rapid decline in the groundwater table, threatening sustainable agricultural development in this region (Wang *et al.* 2002; Kendy *et al.* 2003, 2004; Foster *et al.* 2004). Consequently, it was imperative to adopt water-saving ag-

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riculture to achieve the largest possible increase in water use efficiency (WUE) of crops (Wang *et al.* 2002), keeping yield of winter wheat. Researchers at China Agricultural University have developed a water-saving farming system at the Wuqiao Experimental Station, Hebei, China (Li and Zhou 2000). In this system, we found that high yields can be achieved under reduced irrigation (e.g., two times irrigations instead of four times irrigations) and higher seeding rates (>600 plant m^{-2}) (Zhang *et al.* 2011). With the further decrease in irrigated water resource in future, wheat production may be transformed to rainfed planting in NCP.

Wheat leaves, especially flag leaf, are important photosynthetic assimilation organs during jointing stage and anthesis. But the ear assumes a greater role than flag leaves in supplying assimilates to the grain when drought stress develops (Evans *et al.* 1972; Johnson and Moss 1976; Blum 1985). Chlorophyll contents of non-leaf organs, such as ear, stem and leaf sheath, slowly decrease, and these organs still exhibit a certain degree of photosynthesis in the late grain filling (Lu and Lu 2004).

Wheat spike possesses several advantages, which include vast space for receiving light and CO_2, strong ability of osmotic adjustment, greater surface area than flag leaf (Blum 1985), a higher relative water content (Tambussi *et al.* 2005), and maintenance of a relatively high photosynthetic rate under drought conditions (Tambussi *et al.* 2007). Whole-organ photosynthesis was much higher in the ear than in the flag leaf in well-watered conditions, and as water stress developed, photosynthesis decreased less in the ear than in the flag leaf (Abbad *et al.* 2004). In addition, higher WUE of ear parts than that of the flag leaf is suggested by their lower $\Delta^{13}C$ (Tambussi *et al.* 2007). Genotypic variation in ear morphology is linked to differences in photosynthetic potential to influence grain yield in winter wheat (Rebetzke *et al.* 2016).

The relative contribution of ear photosynthesis to grain yield was more important under abiotic stress (Abbad *et al.* 2004; Tambussi *et al.* 2007; Zhang *et al.* 2013). It may be an important index for cultivar selection in rainfed wheat production. Jiang *et al.* (2003) reported that the wheat production in North China increased significantly in recent 50 years. However, ear as an important organ of grain yield formation, the change of contribution of ear photosynthesis to grain yield during the improvement of winter wheat cultivars is still unclear in China. The response of ear photosynthesis contribution to water supply need to be further studied.

Consequently, the objectives of the paper are to (i) examine the contribution of ear photosynthesis to grain yield and the flag leaf characters of wheat cultivars widely cultivated in China from 1980 to the 2012; (ii) clarify the difference in ear photosynthesis contribution and flag leaf characters between the rainfed and irrigated conditions.

2. Materials and methods

2.1. Experimental field and meteorological conditions

The field experiments were conducted from 2011 to 2013 at Wuqiao Experiment Station of China Agricultural University (37°41´N, 116°37´E, 18 m above sea level), Hebei Province, China. Total annual sunshine hours is 2724.8 h, with an average temperature of 12.9°C. Average frost free growing days are 201 days with annual total precipitation amounts of 562 mm. The precipitation is mainly distributed from June to August.

Soil was clayloam with an average bulk density of 1.5 g cm^{-3} in the upper 100 cm layer. The topsoil (0–20 cm) had a pH of 7.8 (Zhao *et al.* 2015). This field had 11.2 g kg^{-1} organicmatter, 0.8 g kg^{-1} total N, 18.2 mg kg^{-1} available P, and 76.8 mg kg^{-1} K at 0–40 cm soil layer. The underground water level was 6–9 m (Zhang *et al.* 2011). There was 640 mm maximum water storage, 420 mm available water storage, a soil moisture at the maximum field capacity of 21.7% and a wilting coefficient of 7.6% in the upper 200 cm soil layer (Zhang *et al.* 2011). Climatic data and changes of soil water content during the two growing seasons of the experiment were given in Figs. 1 and 2.

2.2. Plant materials and experimental design

Fifteen winter wheat cultivars widely cultivated in NCP from 1980 to 2012 were used in this work. They were Fengkang 13 (released in 1980), Fengkang 8 (1983), Jing 411 (1991), Henong 341 (1998), Jinan 17 (1999), Han 6172 (2001), Shimai 8 (2001), Weimai 8 (2003), Kemai 1 (2003), Hengguan 35 (2004), Jimai 22 (2006), Nongda 211 (2007), Liangxing 66

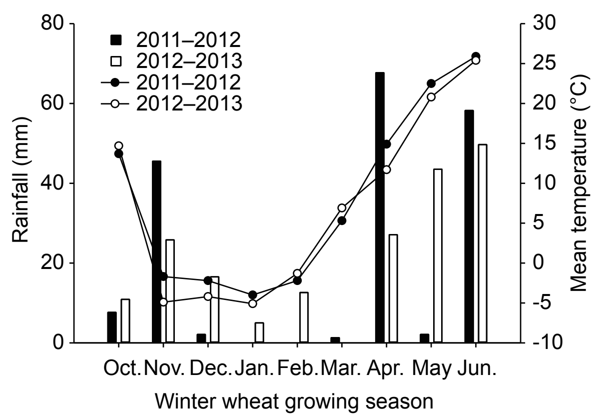

Fig. 1 Monthly rainfall distribution (bar) and mean temperature (line) during winter wheat growth stage in 2011–2012 and 2012–2013.