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RESEARCH ARTICLE

Light interception and radiation use efficiency response to tridimensional uniform sowing in winter wheat

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Abstract

Improving radiation use efficiency (RUE) of the canopy is necessary to increase wheat (*Triticum aestivum*) production. Tridimensional uniform sowing (U) technology has previously been used to construct a uniformly distributed population structure that increases RUE. In this study, we used tridimensional uniform sowing to create a wheat canopy within which light was spread evenly to increase RUE. This study was done during 2014–2016 in the Shunyi District, Beijing, China. The soil type was sandy loam. Wheat was grown in two sowing patterns: (1) tridimensional uniform sowing (U); (2) conventional drilling (D). Four planting densities were used: 1.8, 2.7, 3.6, and 4.5 million plants ha^{-1}. Several indices were measured to compare the wheat canopies: photosynthetic active radiation intercepted by the canopy (IPAR), leaf area index (LAI), leaf mass per unit area (LMA), canopy extinction coefficient (K), and RUE. In two sowing patterns, the K values decreased with increasing planting density, but the K values of U were lower than that of D. LMA and IPAR were higher for U than for D, whereas LAI was nearly the same for both sowing patterns. IPAR and LAI increased with increasing density under the same sowing pattern. However, the difference in IPAR and LAI between the 3.6 and 4.5 million plants ha^{-1} treatments was not significant for both sowing patterns. Therefore, LAI within the same planting density was not affected by sowing pattern. RUE was the largest for the U mode with a planting density of 3.6 million plants ha^{-1} treatment. For the D sowing pattern, the lowest planting density (1.8 million plants ha^{-1}) resulted in the highest yield. Light radiation interception was minimal for the D mode with a planting density of 1.8 million plants ha^{-1} treatment, but the highest RUE and highest yield were observed under this condition. For the U sowing pattern, IPAR increased with increasing planting density, but yield and RUE were the highest with a planting density of 3.6 million plants ha^{-1}. These results indicated that the optimal planting density for improving the canopy light environment differed between the sowing patterns. The effect of sowing pattern×planting density interaction on grain yield, yield components, RUE, IPAR, and LMA was significant ($P<0.05$). Correlation analysis indicated that there is a positive significant correlation between grain yield and RUE ($r=0.880$, $P<0.01$), LMA ($r=0.613$, $P<0.05$), and

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spike number (*r*=0.624, *P*<0.05). These results demonstrated that the tridimensional uniform sowing technique, particularly at a planting density of 3.6 million plants ha^{-1}, can effectively increase light interception and utilization and unit leaf area. This leads to the production of more photosynthetic products that in turn lead to significantly increased spike number (*P*<0.05), kernel number, grain weight, and an overall increase in yield.

Keywords: tridimensional uniform sowing, extinction coefficient, leaf area index, leaf mass per unit area, wheat

1. Introduction

Sowing pattern is an important factor in the sustainable development of agriculture, as it influences plant distribution in the field, which in turn affects traits related to photosynthesis and yield (Liu *et al*. 2011; Yang *et al*. 2014). Adjusting spacing and planting density are two sowing methods often used to improve crop growth and development (Zhang *et al*. 2016). Drilling (D) improves wheat population structure and yield, and many experimental studies have demonstrated that adjusting the spacing of plants in the D mode increases canopy radiation use efficiency (RUE) (Wu and Ou 2014). In the so-called tridimensional uniform sowing (U) mode, wheat seeds are evenly distributed on the same soil plane, so no ridges and rows exist after emergence. Plant growth is strong, the number of panicles per unit area is increased compared with D, and light is evenly distributed and fully utilized, resulting in improved yield (Zhao 2016; ICSCAAS 2016).

Light plays an important role in net primary productivity (Du *et al*. 2015). The availability of light depends upon the spatial distribution of the plant population, and the canopy structure in particular. For example, light interception decreases exponentially from the top to the bottom of the canopy, and leaf net photosynthetic rate (P_n) increases gradually from the bottom to the top of the canopy (Niinemets 2007). These changes in light availability in the canopy are the result of differences in leaf and canopy structural characteristics (Zhang *et al*. 2016). In the growing canopy, leaf traits, such as leaf area index (LAI) and leaf mass per unit area (LMA), are important factors associated with the ability of leaves to collect light and photosynthesize (Yang *et al*. 2017). In general, crop development causes differences in light interception. For example, dry matter (DM) production is always positively correlated with light interception (Zhang *et al*. 2016). The canopy extinction coefficient (K) is an important factor in crop development. This value depends on the canopy structure, species type, and sowing pattern (Soleymani 2016). Intercepted photosynthetically active radiation (IPAR) and radiation use efficiency (RUE) are two other important factors in crop development. RUE is the slope of the linear relationship between biomass production and IPAR (Wang *et al*. 2015). Limited productivity is often due to low RUE. Studies have demonstrated that RUE is determined by variety, temperature (Chaudhary *et al*. 2016), water availability (Yang *et al*. 2017), and nutrition (Zhu *et al*. 2016).

An evenly distributed population is considered to be a good sowing pattern for efficiently capturing the available light resources (Sharratt and McWilliams 2005). In this study, the IPAR and RUE of different planting densities and different sowing patterns were investigated in winter wheat. The objectives were to: (1) compare the effects of canopy on light interception for different planting densities under U and D; and (2) analyze the response of wheat RUE to different planting densities under U.

2. Materials and methods

2.1. Field experiment design

This study was conducted at the Shunyi Experimental Station of the Institute of Crop Sciences, Chinese Academy of Agricultural Sciences in Beijing (40°13´N, 116°65´E) during the wheat growing season from October 2014 to June 2015, and October 2015 to June 2016. The study area is located in a warm temperate, semi-humid, and semi-arid monsoon climate with ample light and heat and an annual total radiation of 5 433 kJ cm^{-2}, annual sunshine hours of 2 608 h, annual mean temperature of 12.3°C, and an altitude of 50.1 m. Mean annual precipitation was 480.7 mm, which was mainly concentrated in July to September when the temperatures were the highest. Monthly mean temperature and precipitation during the growing season are shown in Fig. 1. The winter wheat crop was irrigated with 75 mm water at the jointing and flowering stages. The soil type was sandy loam soil consisting of approximately 50% sand, 10% clay, and 40% silt (IUSS Working Group WRB 2014). The 0–20 cm soil layer contained 13.5 g kg^{-1} organic matter, 95.4 mg kg^{-1} available nitrogen, 13.3 mg kg^{-1} available phosphorus, and 102.5 mg kg^{-1} available potassium.

The variety of wheat used was Zhongmai 8, which has a medium tiller level. Two sowing patterns were used: D and U (Fig. 2). Four planting densities were tested: 1.8, 2.7,