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Effect of sowing time and seeding rate on yield components and water use efficiency of winter wheat by regulating the growth redundancy and physiological traits of root and shoot

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ABSTRACT

A field experiment was conducted to explore the effect of different sowing time and seeding rate on yield components and water use efficiency (WUE) of winter wheat by regulating the growth redundancy and physiological traits of root and shoot. Winter wheat sowing was performed on Oct.12 (T1), Oct.22 (T2), Nov.3 (T3), respectively. There were three treatments of different seeding rates, i.e. 112.5 kg hm^{-2} (D1), 150 kg hm^{-2} (D2) and 225 kg hm^{-2}(D3) in each sowing time. The results showed that sowing time and seeding rate significantly influenced the morphological and physiological characteristics of winter wheat. Plant height, ineffective tiller number, leaf area and root biomass decreased significantly along with the delay of sowing date. Plant height, ineffective tiller number and root biomass increased significantly and leaf area decreased significantly with increasing seeding rate. Under the same seeding rate condition, T1 had the highest number of ineffective tiller, and T3 had the lowest one. Delayed sowing (T2 and T3) increased significantly root activities and leaf photosynthetic rate (P_n) in the late growing stage, and decreased significantly root respiration rate (R_{root}) per unit area of wheat. In the same sowing time treatment, root activities and leaf P_n decreased significantly and R_{root} increased significantly with the increase of seeding rate; however, seeding rate had no effect on root activity and leaf P_n in T3 treatment. Grain yield decreased significantly in T1 and increased significantly in T3 with the increase of seeding rate, and it was the highest in D2 and the lowest in D1 in T2 treatment. Delayed sowing lowered significantly soil water consumption of crop. Under the same sowing time condition, soil water consumption increased significantly as seeding rate increased. WUE decreased significantly with the increase of seeding rate in T1and T2 treatments. In two test years, T2D2 had highest grain yield and WUE, and T3D1 had lowest grain yield and WUE. The interaction of sowing time and seeding rate also had significant effect on soil water consumption, grain yield and WUE. It is clear that appropriate sowing time and seeding rate (T2 Treatmeat) can increase grain yield and WUE of winter wheat by regulating the growth redundancy and physiological traits of root and shoot, but excessive reduction of vegetative organs (T3 Treatmeat) can affect crop production.

1. Introduction

Huang-Huai-Hai Plain is one of the most important winter wheat production regions in north China. Wheat production in this area accounted for 69.3% of total national cereal production (Wei et al., 2017). The rainfall ranges from 100 to 180 mm in North China during the wheat-growing season, far less than the water requirement of winter wheat. Consequently, water scarcity is the most constraint for wheat production in these regions (Zhang et al., 2010). A large amount of irrigation water was commonly used for obtaining a high wheat yield in this region. Due to increasing competition in water usage by industry, domestic consumption, and natural environment, the amount of agricultural water in many areas has become smaller and smaller (Jensen et al., 2010). Efficient use of water in irrigation is becoming increasingly important. However, nowadays, the shortage and serious waste of water are two conflicting aspects in the use of water resources worldwide. Apparently, in order to maintain sustainable production of cereals in this area, it is urgent to develop water-saving agriculture and improve water use efficiency (WUE).

The aim of water-saving cultivation in winter wheat should be to

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keep high yield and improve WUE through appropriate agricultral measures. There is abundant growth redundancy in root system, plant height, leaf area, tiller (or branch) number, and the length of the growth period of crop, etc, (Sheng, 1990) which exerts adverse effect on crop production, since they are major sinks for assimilates, requiring large amounts of photosynthate to produce dry matter. Moreover, the maintenance of these redundant biomass also consumes lots of assimilates and water and fertilizer resources (McCree, 1986). Therefore, it is reasonable to establish a favorable crop population structure with high photosynthetic efficiency and low water consumption, so that to achieve high yield and save water during the process of wheat production. In agricultural practices, sowing time and seeding rate are two important factors affecting the population structure and yield formation of wheat. Appropriate sowing time could make full use of thermal resources before winter, cultivate strong seedling, and improve the population quality as well as grain yield of wheat (Zhang et al., 2016). Early sowing at an appropriate time is one of the most important conventional measures in increasing grain yield of winter wheat, which often facilitates the fast growth of plant while consumes lots of soil water before winter. In order to maintain and increase the photosynthetic production of wheat population during the later growing stage, irrigation quantity must be increased. However, feasible late sowing can inhibit vegetative growth and reduce soil water consumption, which will cut down irrigation water.

Suitable planting density helps to ease the conflict between individuals and populaton by establishing a reasonable populaton structure. It is also beneficial to coordinate development of spike number, spike grain number and grain weight of winter wheat (Wang et al., 2011). The conventional high-yield cultivation of winter wheat advocates building a small population structure with large individuals through seeding early in low density. Under this planting pattern, high yield of wheat depends on large spike and high percentage of tiller ear, which require large quantities of water and fertilizer to promote the development of individual plants. Besides, plants generally have large single leaf area and vigorous secondary root system under this planting pattern (Wang et al., 2006). Leaves are sensitive organs to environmental stress and large leaves are more sensitive to environmental stress than small ones (Ismail et al., 2002; Liu et al., 2003). Once the high temperature and drought happen in later growing stage of wheat, the photosynthesis of leaves decrease rapidly, which will affect grain yield (Xue et al., 2006). The secondary roots mainly distributes in the upper layers of soil. Under water-saving condition, soil moisture in 0–60 cm soil layer dries gradually after flowering. It is difficult for secondary roots to absorb water from the deep soil in late growing stage of winter wheat. In order to maintain the photosynthetic production, plant must expand the deep root system and absorb more water from the deep soil in late growing stage of wheat. In addition to small amounts of the deep secondary roots, the deep root system of wheat comprises primarily the primary roots. Therefore, it is reasonable to increase the number of deep roots and maximize the role of primary roots in the water-saving and high-yield cultivation of winter wheat (Wang et al., 2006). One way of enlarging the proportion of the deep roots is to increase the ratio of primary root in the root system by increasing the seeding rate (Dai et al., 2014). But the seeding rate changes the relative importance of intra-plant competition for light, water, and nutrients during crop growth, thereby strongly influences the use of environmental resources (Hiltbrunner et al., 2007). Previous study showed that increased planting density consumed more soil water before anthesis, decreased grain yield and grain yield per spike (Fang et al., 2010b). In addition, the optimum seeding rate for maximal yield varies with sowing date (Spink et al., 2000; Anderson et al., 2004). Therefore, optimizing seeding rate and sowing date is one management practice to maximize yield and water use.

Based on the above literatures, a hypothesis is that reducing the growth redundancy of root and shoot will help to reduce the consumption of assimilates and water resources. A study on sowing time and sowing date can provide another management option for improving grain yield and WUE of wheat by reducing the growth redundancy of crop and changing water use from the vegetative period to the reproductive period. So far, although there are many studies on the effect of seeding rate and sowing time on the population character and yield of wheat (Li et al., 2005; Dai et al., 2017; Dai et al., 2013; Wang et al., 2011; Zhang et al., 2016), more knowledge is needed on how different seeding rates and sowing times can affect the grain yield and WUE of winter wheat. Therefore, the primary objective of this study was to determine if the grain yield and WUE of winter wheat could be improved by regulating the growth redundancy and physiological traits of root and shoot using different sowing dates and seeding rates. These informations are of great importance to determine the suitable cultivation measures for water-saving and high-yield wheat production and ensure the sustainable utilization of water resources in this area.

2. Materials and methods

2.1. Materials and experimental design

Field experiments were conducted from October 2015 to June 2017 at the soil and fertilizer experimental station of Henan Normal University in the town of Zhaojing, in Huojia County, Henan Province (35°11′N, 113°41′E). The mean annual temperature was 14 °C, the mean annual precipitation was 656.3 mm, and the mean annual pan evaporation was 1,748.4 mm. Fig. 1 is distribution of the monthly precipitation during growing stage of wheat. The primary soil in the area is clay loam soil. Immediately prior to the experiment, nutrient content within the tillage layer (0–20 cm deep) of the soil was measured. The values observed were total nitrogen (N) 1.29 g kg^{-1}, phosphorus 1.0 g kg^{-1}, and organic matter 18.4 g kg^{-1}. The cultivar of winter wheat (*Triticum aestivum* L.) used in the experiment was "Bainong201″, which is widely used by farmers in the region because of its well frost and lodging resistance. Chemical fertilizers (N, P and K) were applied basally at 120, 120 and 120 kg hm^{-2}, respectively. Fertilizer (N) topdressing was at 120 kg hm^{-2} at jointing stage. At jointing and flowering stages, plants were irrigated 70 mm water, respectively. The experiments use split plot design on two factors, including the sowing time (T) and seeding rate (D), winter wheat sowing were performed on Oct. 12 (T1), Oct.22 (T2), and Nov. 2 (T3), respectively. There were three sowing rate treatments, i.e. 112.5 kg hm^{-2} (D1), 150 kg hm^{-2} (D2) and 225 kg hm^{-2}(D3) in each sowing time. Each treatment consisted of three replicated plots and each plot was 4 m × 3 m. Table 1 is season precipitation and accumulated temperature for each sowing date within each growing season.

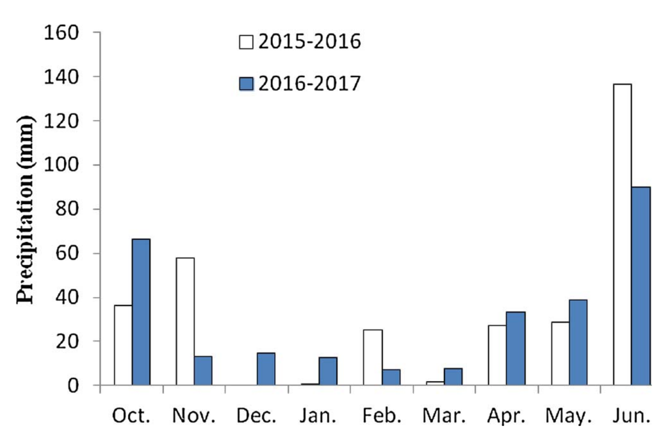

Fig. 1. Distribution of the monthly precipitation during growing stage of wheat.