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Ridge tillage improves plant growth and grain yield of waterlogged summer maize

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ABSTRACT

Regulation of ridge tillage on yield and growth of waterlogged summer maize hybrids Denghai 605 (DH605) and Zhengdan 958 (ZD958) were investigated in field conditions. Results showed that waterlogging significantly decreased leaf area index (LAI), SPAD value, and biomass, resulting in the reduction of photosynthetic rate, thereby decreased grain yield of summer maize. Grain yields of DH605 and ZD958 were decreased by 38% and 42% respectively, compared to no waterlogging treatment. However, ridge tillage was conducive to alleviate the adverse effects of waterlogging on photosynthetic performance and photosynthetic effective radiation by increasing LAI and SPAD value, and improving canopy structure. At tasseling stage (VT), the light transmittance of ear layer in ridge tillage treatment for DH605 and ZD958 was decreased by 12% and 19%, respectively, compared to that of waterlogging treatment. Visibly, ridge tillage effectively alleviated leaf senescence and the decrease of LAI and chlorophyll content induced by waterlogging, and improved canopy structure, photosynthetic effective radiation, and photosynthesis of waterlogged summer maize, and thus increasing grain yield by 39% and 50% for DH605 and ZD958, respectively, compared to waterlogging treatments.

1. Introduction

Waterlogging, due to substantial rainfall, high ground water table or heavy soil texture, is a major abiotic stress for maize growth and yield. Globally, it has been estimated that approximately 10% of all irrigated farmland suffers from frequent waterlogging, which may results in a reduction of crop productivity by 20% (Jackson, 2004). Waterlogging disturbs crops growth and development (Kozlowski, 1997; Jackson and Campbell, 2006), delays growth process, leading to a significant reduction of grain yield (Ren et al., 2014). Waterlogging is one of the most constraints for the production and productivity of summer maize in the Huanghuaihai Plain, China, for most rainfall occurs during the growing season of summer maize. In waterlogged soil, the diffusion of gases through soil pores is strongly inhibited, results in the enhancement of anaerobic respiration and accumulation of harmful substances (such as H_2S, FeS) in soil, which deteriorates rhizosphere environment, and inhibits root growth and development (Przywara and Stcdaniewski, 1999; Ashraf and Rehman, 1999). Waterlogging decreases root dry weight, root/shoot ratio, root active absorption area, and root bleeding rate of summer maize (Kozlowski, 1997; Tan et al., 2010; Ren et al., 2016a). The inhibition of root growth induced by waterlogging, limits the absorption of water and nutrients, disturbs aboveground normal growth and development, and accelerates leaf senescence and loss, and thus results in a significant yield reduction (Kozlowski, 1997). Previous studies have more comprehensively analyzed the effects of waterlogging on growth and development of summer maize. Results show that waterlogging prolongs male and female interval of summer maize (Ren et al., 2014), delays growth process and reduces grain filling rate, dry matter accumulation, and nutrient translation from stem and leaf to grain, ultimately resulting in a significant yield reduction (Ren et al., 2016a, 2016b). Waterlogging damages leaf protective enzyme system, which is due to the increase of malondialdehyde (MDA) content, and the reduction of antioxidant enzyme activity and soluble protein content, thereby leading to the membrane lipid peroxidation, and destruction of biological membrane structure, accelerates leaf senescence process, resulting in the decrease of leaf photo-assimilation (Rusina and Losanka, 2007; Tan et al., 2010). After waterlogging, leaf PSII photosynthesis activity of summer maize is restrained, photosynthetic electron transport is blocked (Yordanova and Popova, 2007), and thus reduces the quantum efficiency of PSII actual electron transfer, leads to a decline of photosynthetic rate, eventually influ-

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encing dry matter accumulation and yield formation (Rusina and Losanka, 2007; Ren et al., 2015).

Currently, summer maize water-resistant technology research mainly focuses on the choice of water-resistant hybrids and application of biochemical preparation, while very little attention has been given to the roles of planting patterns in alleviating the adverse effects of waterlogging on growth and grain yield of summer maize (Zaidi et al., 2003; Ren et al., 2016b). Therefore, by improving cultivation measures to explore effective water-resistant cultivation ways to alleviate the reduction of grain yield induced by waterlogging, is of great significance for ensuring high and stable yield of summer maize. Ridge tillage has been widely applied in wheat, corn, rice, and soy crops, with varying increase of yield (Song et al., 2013). Ridge tillage is conducive to microbial reproduction and growth of surface soil, improve soil activity, enhance soil water-holding capacity and water use efficiency, increase soil temperature and soil aggregate content, resulting in an effectively coordinate relation among soil, water, fertilizer, gas, heat, light, and temperature, etc (Hatfield et al., 1998). To some extent, ridge tillage improves soil structure, increases soil temperature, coordinates the three phase ratio of soil, and improves field microclimate, thereby resulting in the improvement of crop growth and yield (Song et al., 2013). Therefore, ridge tillage has been demonstrated as an effective agronomic practice in dry or cold regions. Ridge tillage can enhance the resistance of spring maize to high temperature stress during the filling stage, and lead to higher yield by directly improving soil moisture and root growth and indirectly improving plant water status, photosynthesis and grain filling (Tao et al., 2013). In addition, ridge tillage can improve drainage and retain runoff from heavy rainfalls, which reduces the risk of crop flooding (Fausey, 1990; Reeder, 1990). Thus it can be seen that ridge tillage can improve crop resistance to stress conditions. However, very little attention has been given to the roles of ridge tillage in alleviating waterlogging damage on summer maize. Moreover, there is lack of research on agricultural waterlogging resistance mechanism of ridge tillage. The objective of this study was to identify the effects of ridge tillage on alleviating the adverse effects of waterlogging on growth and grain yield of summer maize. This study will be useful for providing theoretical and technical support for the establishment of effective water-resistant cultivation ways.

2. Materials and methods

2.1 Plant materials and experimental location

A field trial was conducted at the State Key Laboratory of Crop Biology and the experimental farm of Shandong Agricultural University, China (36°10′N, 117°04′E, 151 m a.s.l.) in 2014 and 2015. The region has a temperate continental monsoon climate. In addition, the effective accumulated temperature during maize growing season in 2014 and 2015 was 1741 °C d and 1711 °C d, respectively. The mean total precipitation was 356 mm and 379 mm, respectively. The topsoil (0–20 cm) of the experimental field is a brown loam, and contained organic matter 10.7 g kg^{-1}, total N 0.9 g kg^{-1}, rapidly available P 50.7 mg kg^{-1} (P), and rapidly available K 86.2 mg kg^{-1} (K).

2.1. Experimental design

The summer maize hybrids Denghai605 (DH605) and Zhengdan958 (ZD958) were used as experimental materials, which are the most widely planted hybrids in China. Maize was sown on June 16 at plant density of 67,500 plants ha^{-1}, 240 kg ha^{-1} urea (N 46%), 686 kg ha^{-1} calcium superphosphate (P_2O_5 17%), and 320 kg ha^{-1} muriate of potash (K_2O 60%) were applied. Before seeding, P and K compound fertilizer was applied one-off to prepare soil for sowing. 40% N compound fertilizer was applied at the sixth leaf stage (V6), and 60% N compound fertilizer was applied at the twelfth leaf stage (V12). Experimental treatment was as follows: waterlogging at the third leaf stage (V3) for 6 days under conventional tillage (WL), waterlogiging at V3 for 6 d under ridge tillage (WL + R, ridge tillage was with ridge scope of 120 cm, ridge surface width of 100 cm, ridge ditch width of 20 cm, and ridge height of 15 cm (Fig. 1). Summer maize was sowed in ridge surface, with row spacing of 60 cm and plant spacing of 24.5 cm, at plant density of 67,500 plants ha^{-1}), and no waterlogging under conventional tillage (CK). Every experimental treatment unit was 120 m^2 (6 m wide × 20 m long). There was 3.0 m interval among each experimental plot, and 0.4 m high ridge around each plot, in order to prevent water. Each waterlogged plot was provided with a separate supply of water through water pipe. The water in waterlogged pool was maintained at 2–3 cm above the soil surface through the water valve to control water flow during waterlogging period.

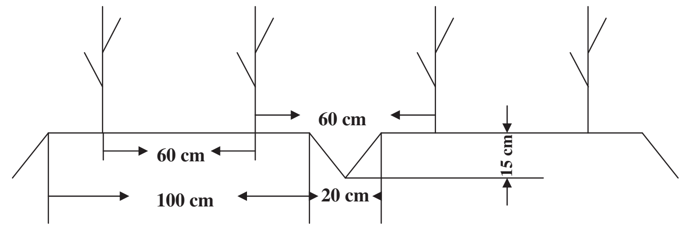

Fig. 1. Chart of ridge planting.

2.2. Sample collection

2.2.1. Biomass

Five representative plants were sampled from each plot at the sixth leaf stage (V6), twelfth leaf stage (V12), tasseling stage (VT), milk stage (R3), and physiological maturity stage (R6) according to Ritchie and Hanway (1982). Samples were preserved after being separated into stems and leaves at V6, V12, and VT, and into stems, leaves, and ears at R3 and R6. Dry matter of each component was determined at 80 °C in a force-draft oven (DHG-9420A, Bilon Instruments Co.Ltd, Shanghai, China) to constant weight, and weighed separately.

2.2.2. Leaf area index

At V6, V12, VT, R3, and R6 stages, leaf area was calculated as leaf length (L) × maximum leaf width (W) × 0.75. Ten plants per plot were randomly selected to measure. LAI was calculated as follow (Qi et al., 2012).

$$\mathrm{LAI} = \mathrm{leafarea}(\mathrm{m}^2\mathrm{plant}^{-1}) \times \mathrm{plantnumberm}^{-2}$$

2.2.3. SPAD value

The SPAD values of functional leaves were measured on the middle of the uppermost, fully expanded leaves between 10:00 and 12:00 at the V6, V12, VT, and R3 stages using a chlorophyll meter (SPAD-502, Soil-plant Analysis Development Section, Minolta Camera Co., Osaka, Japan). Ten plants per plot were randomly selected for measurements.

2.2.4. Leaf gas exchange parameters

At the V6, V12, VT, and R3 stages, the photosynthetic rates (P_n), stomatal conductance (G_s), and intercellular CO_2 concentration (C_i) of functional leaves were measured using a portable open infrared gas analyzer system (CIRAS II, PP System, Hansatech, UK). Five plants were measured for each plot on clear days between 10:00 A.M. and 12:00 P.M. Measurement conditions were kept consistent: LED light source, and the PAR was 1 600 μmol m^{-2}. Flow rate