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The length of micro-sprinkling hoses delivering supplemental irrigation affects photosynthesis and dry matter production of winter wheat

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ABSTRACT

A shortage of water threatens agricultural sustainability in the Huang-Huai-Hai Plain of China. Effective water-saving technologies need to be developed urgently. The experiment reported here, conducted between 2010 and 2012, aimed to determine how the length of the micro-sprinkling hose delivering supplemental irrigation affected photosynthetsis, dry matter (DM) accumulation, grain filling, and yield of winter wheat. Four treatments were compared: rainfed (W0) and irrigated with micro-sprinkling hoses with lengths of 40 m (W40), 60 m (W60), and 80 m (W80). The relative soil water content in the 0–140 cm soil horizon (RSWC) did not differ between 0 and 40 m from the proximal border of irrigated plots either in W40 or W60, and no differences in RSWC were observed across four inter-rows, spaced 22.9 cm apart, from the micro-sprinkling hoses in W40. However, RSWC decreased significantly with increasing distance from the proximal border in W80. There were no differences in mean actual photochemical efficiency (ΦPSII), maximum quantum yield of the PSII (*Fv*/*Fm*), flag leaf photosynthetic rate (*Pn*) or canopy apparent photosynthetic rate (CAP) 20 days after anthesis (DAA) between plants from W40 and W60, but all were greater in plants from W40 and W60 than in plants from W80. The ΦPSII, Fv/Fm, Pn, and CAP in plants from W80, but not W40, decreased significantly with increasing distance from the proximal border from 20 DAA. The total DM and the harvest index of plants from W40 were greater than those of plants from W60 and W80. The grain filling rate in the middle and later filling stages, 1000-grain weight, grain yield and water use efficiency became less as the length of micro-sprinkling hose was increased from 40 m to 80 m. In this study, the optimum length of micro-sprinkling hoses for irrigating wheat after jointing was 40 m to 60 m. The results indicate the importance of uniformity of irrigation water distribution in increasing the productivity of winter wheat.

1. Introduction

Winter wheat (*Triticum aestivum* L.) production in the Huang-Huai-Hai Plain (Shi et al., 2013) accounts for approximately 60% of all wheat production in China, where wheat was sown on 2.43×10^7 ha of land and yielded 1.21×10^8 t grain in 2012 (National Bureau of Statistics of China, 2013). However, precipitation in this region during the winter wheat growing season is only 150 mm–180 mm, which does not fully satisfy the water requirement of this crop (Li et al., 2008; Liu et al., 2011). Thus, supplemental irrigation (SI) is employed to provide the additional water required for wheat production. Surface irrigation is widely used in this region (Liu et al., 2013) and more than 80% of the surface water and groundwater resources have been exploited for irrigation (Sun et al., 2006). The excessive exploitation of groundwater has caused the groundwater level to fall and created many environmental problems (Hu et al., 2010), which threaten the sustainability of agriculture in this region.

Various advanced, water-saving techniques have been employed to improve the efficiency of water-use in agriculture. Pereira (1999) proposed that level-basin irrigation might be employed instead of traditional surface irrigation methods to achieve water savings and increase water productivity. Wang et al. (2013b) suggested that, compared with the level-basin irrigation method, employing drip irrigation could reduce required SI by 18–61 mm, increase grain yield of winter wheat by 129 kg ha^{-1},

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and improve water use efficiency (WUE) of winter wheat by 0.16 kg m^{-3}. Bandyopadhyay et al. (2010), Liu et al. (2013) and Yao et al. (2005) found that sprinkler irrigation could not only decrease the SI required, but also enhanced the photosynthesis of flag leaves, dry matter accumulation, grain yield, harvest index, and WUE of winter wheat. Irrigation with micro-sprinkling hoses is one of the water-saving irrigation methods that combine the advantages of both drip and sprinkler irrigation (Zhou et al., 2003). Compared with surface irrigation, irrigation using micro-sprinkling hoses can reduce the water consumption of various crops by 10% to 40%, and increases yield and WUE by 15–19% and 25%, respectively (Home et al., 2002; Zhou et al., 2002; Liu, 2008). Furthermore, irrigation using micro-sprinkling hoses is relatively simple and inexpensive (Zhang et al., 2009).

Micro-sprinkling hoses are made of thin-walled plastic and have many orifices (MOA, 2007). The sprinkling angle (i.e. the angle between the tangent of the initial water jet and the horizon) and the length of the hose are two important factors affecting the uniformity of SI water distribution, because they affect the firing range and the loss of pressure in the hose, respectively (Zhang et al., 2009). In a previous study, we reported the design of a novel micro-sprinkling hose suitable for delivering SI to winter wheat, and observed that a sprinkling angle of 80° provided greatest uniformity of water distribution in soil and, thereby, supported largest crop yields following irrigation (Man et al., 2013, 2014). However, the effects of the length of the micro-sprinkling hose on the distribution of irrigation water in soil and crop yield were not reported. The objectives of this study were, therefore, (1) to investigate the effect of the length of the micro-sprinkling hose on the uniformity of water distribution in soil following irrigation, and (2) to determine the relationships between the uniformity of the soil water distribution and photosynthesis, dry matter accumulation, grain filling and grain yield of winter wheat.

2. Materials and methods

2.1. Experimental site

Field experiments were conducted from October 2010 to June 2012 in Shijiawangzi village, Yanzhou, Shandong Province, China (116°41′E, 35°42′N). This village is located at the center of the Huang-Huai-Hai Plain, and the environment is typical and representative of the plain. The area has a warm temperate semi-humid continental monsoon climate, annual average temperature of 13.6 °C, annual accumulated sunshine hours of 2460.9 h, and average annual precipitation of 720 mm. The groundwater depth was 25 m and the total rainfall during the experiments was 661.8 mm in 2010/2011 and 803.0 mm in 2011/2012. The soil is a cinnamon soil (CRGCST, 2001). The organic matter, total nitrogen, available phosphorus, and available potassium in the topsoil (0–20 cm) of the experimental plots were 15.3 g kg^{-1}, 1.1 g kg^{-1}, 29.9 mg kg^{-1}, and 124.0 mg kg^{-1}, respectively. The field slope was 0.22%. Details of the soil bulk density and soil moisture of 20 cm layers in the top 0–200 cm of the soil can be found in Man et al. (2014).

2.2. Experimental design

Four treatments were compared: rainfed (W0) and irrigated with micro-sprinkling hoses with lengths of 40 m (W40), 60 m (W60), and 80 m (W80). The minimum sprinkling angles (i.e. the angle between the tangent of the initial water jet and the horizontal) of the micro-sprinkling hoses were 80°, and all details of the arrangement of orifices can be found in Man et al. (2014).

All the micro-sprinkling hoses had folded diameters of 60 mm, and were perforated with 57 groups of orifices per 20 m. A total of six orifices were in each group. Within a group, the diameter of the first and the sixth orifices was 1.2 mm and the diameter of the other four orifices was 0.8 mm. The distance between two adjacent groups of orifices was 20 cm.

Each treatment was replicated three times in a randomized complete block design. A 1.0 m wide unirrigated zone was maintained between adjacent plots to minimize the effects of adjacent treatments. Each experimental plot consisted of eight rows of wheat that were spaced 22.9 cm apart. The rows of winter wheat were designated r1 to r8 (Fig. 1), and inter-row spaces between wheat rows were designated L1 to L7. The micro-sprinkling hose was laid in L4. A pressure-regulated valve and a flow-meter were installed at the head of all micro-sprinkling irrigation systems to control the system working pressure and to measure the applied water. The working pressure was 0.02 MPa and the flow rates were 6.4 and 6.8 m^3 h^{-1} for 40 m and 80 m lengths of hose in 2010/2011, respectively, and 6.0, 6.4, and 6.6 m^3 h^{-1} for 40 m, 60 m, and 80 m lengths of hose in 2011/2012, respectively.

2.3. Crop management

All plots were supplied with 240 kg N ha^{-1}, 150 kg P_2O_5 ha^{-1}, and 150 kg K_2O ha^{-1}. All P and K fertilizers and half of the N fertilizers were applied pre-sowing, and the remaining N fertilizer was top-dressed at the jointing stage (first node detectable). The high-yielding wheat (*Triticum aestivum* L.) cultivar Jimai22 was used in the experiments. Wheat seeds were sown at 180 seed m^{-2} on October 8 and October 10 in 2010 and 2011, respectively. The shoots of wheat seedlings ceased growth at the beginning of December and commenced growth again at the end of February. During this period the average daily temperature was below 0 °C. Wheat plants were harvested on June 14, 2011, and on June 13, 2012.

2.4. Irrigation management

Crop developmental stages were categorized using the Zadoks scale (Zadoks et al., 1974). Two irrigation events occurred during the growing season: the first at Z31 (first node detectable) and the second at Z61 (beginning of anthesis). Irrigation was performed in the morning when the wind speed was less than 1.0 m s^{-1}. The amount of SI matched the crop irrigation requirement (CIR), which was calculated from the relative soil moisture content in the 0–140 cm soil layer as described by Man et al. (2014). The target relative soil water content in the 0–140 cm soil horizon after SI was 75% field water capacity (FC) at jointing and 70% FC at anthesis in 2010–2011, and 70% FC at both jointing and anthesis in 2011–2012. Field water capacity was defined as the water content of a soil following saturation with water when free drainage is negligible. The CIR for different treatments is shown in Table 1.

2.5. Soil water distribution after SI

Soil samples were collected using a soil corer at 20 cm increments down to 200 cm in all experimental plots. The soil water content (gravimetric water content, mg water g^{-1} dry soil) was determined using the oven-drying method (Gardner, 1986). The relative soil water content (RSWC) was calculated as soil water content divided by FC and expressed as a percentage. Measurements were performed before sowing, 1 day before irrigation at both jointing and anthesis, 3 days after irrigation at both jointing and anthesis, and at maturity. Subplots A, B, C, D, and E were located 0–2 m, 19–21 m, 38–40 m, 58–60 m, and 78–80 m from the proximal border of a plot (Fig. 1). In W40, there were A, B, and C subplots. In W60, there were A, B, C, and D subplots. In W80, there were A, B, C, D, and E subplots. Three soil samples were taken at random locations from each subplot in L1, L2, L3, and L4.