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RESEARCH ARTICLE

Effects of different irrigation methods on micro-environments and root distribution in winter wheat fields

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Abstract

The irrigation method used in winter wheat fields affects micro-environment factors, such as relative humidity (RH) within canopy, soil temperature, topsoil bulk density, soil matric potential, and soil nutrients, and these changes may affect plant root growth. An experiment was carried out to explore the effects of irrigation method on micro-environments and root distribution in a winter wheat field in the 2007–2008 and 2008–2009 growing seasons. The results showed that border irrigation (BI), sprinkler irrigation (SI), and surface drip irrigation (SDI) had no significant effects on soil temperature. Topsoil bulk density, RH within the canopy, soil available N distribution, and soil matric potential were significantly affected by the three treatments. The change in soil matric potential was the key reason for the altered root profile distribution patterns. Additionally, more fine roots were produced in the BI treatment when soil water content was low and topsoil bulk density was high. Root growth was most stimulated in the top soil layers and inhibited in the deep layers in the SDI treatment, followed by SI and BI, which was due to the different water application frequencies. As a result, the root profile distribution differed, depending on the irrigation method used. The root distribution pattern changes could be described by the power level variation in the exponential function. A good knowledge of root distribution patterns is important when attempting to model water and nutrient movements and when studying soil-plant interactions.

Keywords: border irrigation, root profile distribution, sprinkler irrigation, surface drip irrigation, field micro-environment, winter wheat

1. Introduction

Each plant species has its own root growth characteristics, which can be substantially modified by the plant's environment (Bathke *et al.* 1992). The physical, chemical, and microbiological conditions throughout the soil profile, together with the plant microclimate, should be considered when investigating plant root growth characteristics.

Soil physical properties, such as particle size distribution, bulk density, soil aeration, soil water potential, soil

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strength or penetration resistance, and temperature, can all affect root growth temporally and spatially (Merrill and Rawling 1979; Unger and Kaspar 1994). Zimmerman and Kardos (1961) researched the effect of bulk density on root growth. Their results showed that the greater the soil bulk density, the lower the root weight. Soil water content or water potential also had considerable effects on root growth. Adventitious roots formed, but did not elongate when the soil water content around the crown node was low. However, adventitious root growth appeared normal when the water potential was at or above 15 bars (Ferguson and Boatwright 1968). High levels of available water can lead to relatively low below-ground biomass (Fabião *et al.* 1995) and reduced root initiation as the depth increases (Torreano and Morris 1998) because adequate water can be accessed by surface roots. In contrast, water deficit stress resulted in a greater proportion of the roots growing deeper into the soil (Bai and Li 2003; Benjamin and Nielsen 2006). Soil temperature affects the growth of root system components, initiation and branching, orientation and direction of growth, and root turnover. Kaspar and Bland (1992) showed that as the temperature increased, roots grew faster and reached a maximum growth rate at about 30°C for maize (*Zea mays*) and pecan (*Carya illinoinensis*), after which the rate began to decrease. Kar *et al.* (1976) investigated the effects of variations in temperature regime on rice root growth in association with other soil physical properties. The results indicated that high temperature increased root degeneration, but the high bulk density of the sandy loam soil decreased root degeneration.

In addition, soil chemical properties also affect root development. Nielsen *et al.* (1960) found that phosphorus fertilizer could increase the root growth of oats (*Avena sativa*). Nitrogen fertilization has been found to increase root weights at all soil moisture levels (Kmoch *et al.* 1957). However, Jackson and Bloom (1990) suggested that tomato root systems showed lower responses to fertilizer N because of changes in the root distribution pattern. The influence of atmospheric humidity on root growth has also been studied (Breazeale and Mcgeorge 1953) and the results showed that root elongation significantly increased when the atmosphere changed from arid to humid. The results also indicated that sprinkler irrigation, which simulates a rain, may stimulate more root growth than conventional methods of irrigation in semiarid districts.

In irrigated fields, each irrigation method used has different effects on the microclimate and soil environment. Tolk *et al.* (1995), Liu and Kang (2006) and Cavero *et al.* (2009) showed that the air temperature and vapor pressure deficit were lower in a sprinkler irrigated field than in a surface irrigated field. Other studies showed that the topsoil in sprinkler irrigated fields was looser than in surface irrigated fields (Sun 2006). Soil water dynamics are also differentially affected by the type of irrigation method used. Frequent irrigations by micro-irrigation can help to maintain higher average soil water contents than conventional methods when using the same amount of water (Rawlins and Roats 1975). Furthermore, Wang *et al.* (1997) and Home *et al.* (2002) found that surface irrigation appeared to leach chemicals more rapidly than both drip and sprinkler irrigation, which resulted in different nutrient distribution patterns. Therefore, the type of irrigation method used affects a plant's environment, which would lead to variations in root growth and profile distribution.

Root water uptake patterns under traditional border irrigation (BI) (a kind of surface irrigation), sprinkler irrigation (SI), and surface drip irrigation (SDI) have been investigated previously (Lü *et al.* 2010). In this study, we investigated soil and micro-environmental characteristics under winter wheat, such as relative humidity within the canopy, soil temperature, topsoil bulk density, soil matric potential, and soil available nutrients, and their effect on root distributions when subjected to three different irrigation methods. In order to make accurate comparisons, the same amount of water was applied under each irrigation treatment. The objectives of this study were to research the micro-environments and root distribution pattern changes for winter wheat when treated with the different irrigation methods. A good knowledge of how the root profile distribution is affected by irrigation methods is very important when attempting to model how water and nutrient dynamics are influenced by irrigation. This information should lead to improvements in irrigation scheduling.

2. Results and discussion

2.1. Precipitation and irrigation

Precipitation values from the jointing stage (174 days after sowing (DAS)) to harvesting (249 DAS) in 2008 and 2009 are shown in Fig. 1. In 2008, total precipitation was 102.3 mm, there were 21 rainfall events, and precipitation was relative uniformly distributed. In 2009, total precipitation was 98.4 mm, there were 13 rainfall events, but precipitation was scarce from the flowering stage (204 DAS) to the grain-filling stage (239 DAS). In addition, from 174 to 249 DAS, the average air temperature in 2009 was 19.0°C, which was higher than in 2008 (17.7°C) (Fig. 1); and the average air relative humidity (RH) in 2009 was 59.9%, which was lower than in 2008 (71.3%). Therefore, it was wet and rainy in 2008, compared to 2009.

The first irrigation in each treatment was carried out at the jointing stage in 2008 (177 DAS) and 2009 (174 DAS). The number of water applications varied with irrigation method