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Research paper

Identifying drought-tolerant genotypes of barley and their responses to various irrigation levels in a Mediterranean environment

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ABSTRACT

Improved water use efficiency (WUE) for barley (*Hordeum vulgare* L.) production in the arid and semi-arid regions is necessary to save the limited water resources available for irrigation. A field study was conducted in 2014–2015 and 2015–2016 growing seasons on sandy soil under drip irrigation system. Objectives were to identify drought-tolerant genotypes of barley that are less susceptible to water stress and determine the impact of various irrigation levels on yield attributes, grain yield, WUE of those genotypes compared with drought-sensitive genotypes in an arid Mediterranean latitude. Treatments included four irrigation levels (severely-low 120 mm, low 240 mm, medium 360 mm, and high 480 mm) and seventeen barley genotypes. Plants exposed to water stress showed significant plant height and yield attributes decrease compared with well-watered plants. The high irrigation level had the greatest grain yield of 4284 kg ha^{-1} and lowest WUE of 6.7 kg ha^{-1} mm^{-1}. The WUE of aboveground biomass was also decreased to 16.2 kg ha^{-1} mm^{-1} for the high irrigation level compared with 28.3 kg ha^{-1} mm^{-1} for the severely-low irrigation level. Drought-tolerant genotypes managed to produce more yield with higher WUE compared with drought-sensitive genotypes. Maximum grain yield of 4966 kg ha^{-1} was obtained at 482 mm of irrigation water for drought-tolerant genotypes while drought-sensitive genotypes had maximum grain yield of 3513 kg ha^{-1} at 561 mm of irrigation water. These results suggest that improved irrigation management using drip irrigation system and the use of drought-tolerant genotypes can increase water productivity to conserve the limited water resources in arid Mediterranean environments.

1. Introduction

Water shortage is one of the major limitations of crop production in arid and semiarid regions. Water shortage combined with uncertainty of climate change are expected to bring challenges to crop production and food security in many areas of the world. Temperature and precipitation patterns are expected to change, but the magnitude and intensity of this change are difficult to predict (Hatfield et al., 2011). However, historical weather dataset suggest that temperature is expected to increase by 0.8–1.0° C and more drought events are expected to occur (Seager et al., 2007). Some regions, such as Mediterranean latitudes, are expected to experience increases in the frequency and intensity of drought (Robredo et al., 2007). In this scenario, supplemental irrigation generally contributes beneficially to crop growth and yield. However, irrigating to meet the maximum daily water requirements is challenging in light of water shortage and increased pumping costs.

Conserving water resources is possible through deficit irrigation, which is defined as the application of irrigation water less than full crop water requirements (Attia et al., 2015). Supplemental irrigation can also be considered as deficit irrigation that is used to prevent dryland yield fluctuations (Fereres and Soriano, 2007; Attia and Rajan, 2016). Previous research reported that deficit irrigation did not reduce the yield and increased water use efficiency compared with full irrigation in semiarid regions (Kang et al., 2002; Sun et al., 2006; Attia et al., 2016a). In this context, the use of efficient irrigation system such as drip irrigation can have water saving potentials due to the precise application of water with high degree of uniformity and frequency (Hansona et al., 1997; El-Hendawy et al., 2008).

Barley is one of the main cereal crops grown in Mediterranean areas (Shakhatreh et al., 2001; Samarah et al., 2009; Araya and Stroosnijder, 2010). In the arid and semiarid regions, barley growth and yield are strongly impacted by the limited available water

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for irrigation (Forster et al., 2004; Cossani et al., 2012). Barley is a drought-tolerant crop; however, water stress during booting and heading led to decrease in chlorophyll content and photosynthetic rate and increase in stomata resistance (Ghotbi-Ravandi et al., 2014). Others found several physiological changes to occur in barley when exposed to drought stress that included decreased water potential (Sánchez-Díaz et al., 2002; Samarah et al., 2009), increased stomata closure (Sayed, 2003), and decreased CO_2 uptake and assimilation rate (Medrano et al., 2002). These physiological alterations in turn affect grain yield and yield attributes such as spikes m^{-2}, grain $spike^{-1}$, grain weight $spike^{-1}$ (Del Moral et al., 2005; Jamieson et al., 1995; Samarah et al., 2009).

Genotypes from different genetic background usually vary in their responses to the environment which called genotype-environment interaction. This interaction further complicates breeding work because of difficulties in predicting how genotypes will perform under different sets of environmental conditions (Ceccarelli, 1989; Shakhatreh et al., 2001). Thus, identifying drought-tolerant genotypes for more efficient water use is needed to mitigate the negative impacts associated with drought stress under the arid and semiarid Mediterranean conditions (Barnabás et al., 2008; Gleick and Palaniappan, 2010; Çolak et al., 2015). Drought-tolerance genotypes has the ability to produce more yield with less water than drought-sensitive genotypes which are, in general, more susceptible to drought stress (Turner, 1979; Hall, 1993; et al., 1998 Ramirez-Vallejo and Kelly, 1998). Previous research has addressed the use of drought-tolerant genotypes of barley in improving crop productivity under Mediterranean latitudes (Tester and Bacic, 2005; Samarah et al., 2009; Ceccarelli et al., 2010). Evaluation of these genotypes is recommended to be done under both stress and non-stress conditions (Mardeh et al., 2006; Nouri et al., 2011). Several drought-tolerant indices such as stress drought index and stress susceptibility index were reported for being effective in discriminating among genotypes (Rosielle and Hamblin, 1981; Bouslama and Schapaugh, 1984; Hossain et al., 1990; Gavuzzi et al., 1997).

Water use efficiency (WUE) defined as the ratio of produced yield to total seasonal water use considers as an important factor in characterizing the performance of drought tolerance genotypes (Blum, 2009). Therefore, it could be used as a criterion for yield improvement under drought stress and as an indication of the ability of genotypes to conserve water under stress conditions (Rebetzke et al., 2002; Richards, 2006; Fang et al., 2010; Dong et al., 2011). Gaps remain in knowledge of how yield attributes, grain yield, aboveground biomass, and WUE of different barley genotypes respond to various irrigation levels in arid high pH sandy soils. Objectives of present research were to (i) identify drought-tolerant genotypes of barley that are less susceptible to drought stress in water limited environments and to (ii) determine the impact of various irrigation levels on yield and WUE of drought-tolerant genotypes compared with drought-sensitive genotypes of barley in a Mediterranean environment.

2. Materials and methods

2.1. Site description and cultural practices

A field study was conducted in 2014–2015 and 2015–2016 at Khattara Research Station, Sharqia, Egypt (30°41′N, 31°51′E, altitude 13 m) on sandy soils. Soil samples were taken (four cores/sample per replicate) before sowing from the 0–0.3, 0.3–0.6, and 0.6–0.9 m soil depths in both years of the study. Samples were analyzed to determine soil pH and associated chemical properties (Table 1). Based on soil analysis, the soil is sandy throughout the profile (76.8% coarse sand, 17.4% fine sand, 4.4% Silt, and 1.5% clay) with high pH level. Soil bulk density was determined using cylinders 70 mm wide and 100 mm height (Grossman and Reinsch 2002). Soil field capacity and wilting point were determined using the method described by Cassel (1986). Average monthly temperature, precipitation, growing degree days based on 0 °C baseline, and relative humidity during barley growing seasons of 2014–2015 and 2015–2016 as well as long-term minimum and maximum temperature and precipitation are shown in Table 2. The climate is arid with average annual precipitation less than 80 mm that is distributed during winter from November to April (El-Nahrawy, 2011).

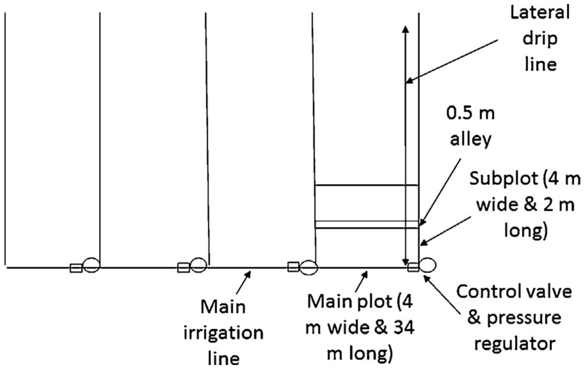

Fig. 1. Layout of one replicate showing location of irrigation treatments in the main plots and barley genotypes in the subplots.

Barley was sowed on 21 November in 2014 and 24 November in 2015 at a seeding rate of 300 seeds m^{-2} for an average plant population of 3 million plants ha^{-1}. The field was irrigated using drip irrigation system with drip laterals spaced 0.4 m apart and 0.30-m emitter spacing. Each irrigation sector had a control valve and pressure gauge to maintain the operating pressure at 1 bar and emitter flow rate of 4 Liters h^{-1}. A flow meter was used to measure the targeted irrigation water amount for each irrigation level. An initial irrigation of 38 and 46 mm was applied two days before sowing in 2014–2015 and 2015–2016, respectively to ensure uniform emergence. Typical cultural practices used by local producers were used in this study. Nitrogen was applied at a rate of 180 kg N ha^{-1} as ammonium sulfate (21% N) in five equal splits from emergence to tillering. Phosphorus and potassium were applied before sowing at a rate of 30 kg P ha^{-1} as superphosphate (15.5% P_2O_5) and 100 kg K ha^{-1} as potassium sulfate (48% K_2SO_4). Post emergence herbicides Granstar 75% DF [Tribenuron methyl (Sulfonyl urea), 750 g/kg] was used in a dose of 15 g ha^{-1} for broad leaf weed control and Axial XL (Pinoxaden and Cloquintocet-mexyl) was used in a dose of 0.6 L ha^{-1} for grass weed control. There were no pest or weed pressure in both years of the study.

2.2. Experimental design

The experimental design was a randomized complete block with a split plot arrangement in three replicates (Fig. 1). Each main plot was 4 m wide (20 0.20-m rows) and 34 m long. Subplots were randomly assigned within the main plots and were 4 m wide and 2 m long with a 0.50-m alley between subplots. Main plots consisted of four irrigation levels and subplots consisted of seventeen barley genotypes. Irrigation levels were severely-low, low, medium, and high which represented 120, 240, 360, and 480 mm of irrigation water, respectively. The four irrigation schedules applied during barley growing seasons of 2014–2015 and 2015–2016 are shown in Table 3. These amounts of irrigation water were determined based on above and below-average irrigation applied for barley in the study region. Irrigation was applied once every ten days from tillering to heading and once every week from heading to maturity and was terminated two weeks before harvest on 1