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The effects of different deficit irrigation strategies on yield, quality, and water-use efficiencies of wheat under semi-arid conditions

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ABSTRACT

Central Anatolia is known as the wheat silo of Turkey since the region has the greatest production of wheat in the country. However, the region's insufficient water resources force producers to use deficit irrigation. The present study was conducted to create deficit irrigation strategies for wheat. Twenty two experimental treatments, including full irrigation and dry treatment, were created based on the different growth stages of wheat (stem elongation, heading, milk stage) and water-deficit levels (0, 35, 65 and 100%). The results revealed different effects of water-deficits on wheat yield, quality, and water-use efficiencies based on the plant-growth stages in which the water deficits are applied. The water deficits applied in the stem elongation and heading stages significantly decreased the wheat yields. On the other hand, a 35% deficit applied only in the stem elongation stage yielded the highest thousand-kernel weight and protein ratio. The seasonal water-consumptive use of experimental treatments varied between 206 and 571 mm; the grain yields varied between 288 and 682 kg da^{-1}; the thousand kernel-weights varied between 33.9 and 52.2 g; the total water-use efficiencies varied between 1.02 and 1.30 kg m^{-3} and irrigation water-use efficiencies varied between 0.51 and 1.17 kg m^{-3}.

1. Introduction

Wheat is the most significant cereal in human nutrition and is thus cultivated worldwide over large areas. With 219,046,706 ha cultivated lands (constituting 32% of total cereal cultivated lands worldwide), it occupies the first place among other cereals (FAO, 2015). Wheat is also the most common cereal in Turkey with 7,900,000 ha of cultivated lands and 19 million tons of production. Of this annual production, 36% comes from the Central Anatolia Region including the Konya Plain (TUIK, 2015a).

The Konya plain is the region with the least precipitation in the whole country. Therefore, the region is also the poorest region of Turkey in terms of surface-water resources. Although wheat is commonly cultivated in regions with relatively precipitated winters and springs, precipitations are mostly insufficient for optimum yields and, therefore, supplemental irrigation is required throughout various parts of the country. Due to insufficient irrigation resources, only 12% of wheat lands are irrigated (TUIK, 2015b). Groundwater is widely used to irrigate the plain's summer crops due to the deficit in surface-water resources. Widespread use of pressurized irrigation systems in the plain results in excessive groundwater withdrawals and consequently a couple of meter drops in groundwater levels each year. Such drops in groundwater levels also raise the energy costs of irrigation (Yılmaz, 2010).

The plant–soil–water relationships need to be well understood to enable efficient water use and management of agriculture. Therefore, deficit-irrigation approaches have been developed to respond to possible changes in water resources. There is a continuing effort to understand the relationships between soil water balance, crop yield, and water-use efficiency in order to develop better semi-arid crops and water management practices (Musick et al., 1994; Wiedenfeld, 2000; Halitligil et al., 2000).

Since land allocated for wheat production cannot be increased, the ability to increase water-use efficiency is considered to be the most important tool for increasing crop production, and saving water and the environment. A reasonable irrigation schedule is a key factor to help farmers increase their crop yields and save water, especially in water-deprived regions (Liu et al., 2013).

Under insufficient water-resource conditions, a deficit-irrigation approach involves using less water than the required amounts throughout the plants' growing season (Musick et al., 1994; Kipkorir, 2002; Pereira et al., 2002; English et al., 2002; Debaek and Aboudrare, 2004; Fereres and Soriano, 2007; Ali and Talukder, 2008; Behera and Panda, 2009; Blum, 2009; Farre and Faci, 2009; Geerts et al., 2009). Deficit irrigation is the application of less water than required for potential ET and maximum yield, resulting in the conservation of limited irrigation water (Musick et al., 1994; English et al., 2002). Therefore, deficit irrigation almost

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always increases water use efficiency because the applied water is less than the depletion by ET, and most or all of the applied water remains in the root zone (Fereres and Soriano, 2007).

A water stress may be exerted on plants, and consequently yield decreases may be observed under deficit-irrigation conditions. However, such concerns may be eliminated by applying sufficient amounts of water during periods in which plants are sensitive to water deficit and applying water deficits during periods in which plants are more resistant to water deficiencies (Blum, 2009; Geerts et al., 2009). Several researchers concluded that deficit irrigation could increase a farm's net income (English et al., 1990; Martin et al., 1989; Kumar and Khepar, 1980; Zhang et al., 2002; Fardad and Golkar, 2002). The potential returns of deficit irrigation derive from three factors: increased irrigation efficiency, reduced cost of irrigation and the opportunity to reduce the cost of water (English et al., 1990). Under some circumstances, maximum attainable income for an irrigated field may be achieved by deficit irrigation, the deliberate under-irrigation of the crop. This assertion is supported by economic theory and past research studies (English and Nuss, 1982; Hargreaves and Samani, 1984; James and Lee, 1971).

A slight decrease in yields may be allowed in deficit irrigation operations. However, the yield obtained from the area to be irrigated with saved water may exceedingly compensate such yield losses (English et al., 2002). Under limited irrigation, reductions in grain yield due to restricted water availability depend on the degree, duration and timing of the imposed soil-moisture deficit. The impact of soil-moisture deficit on crop yield depends on the particular phenological stage of the crop and the most sensitive stage can exhibit variations from one region to another (Singh et al., 1991).

Because of differences related to regional variability in environmental and agronomic practices, information specific to a region is needed to develop and refine limited irrigation strategies. Crop response to water stress during different growth stages has practical implications for irrigation scheduling. Previous studies showed that wheat was not equally sensitive to water stress at different growth stages (Schneider et al., 1969; Eck, 1988; Zhang and Oweis, 1999). It has been repeatedly stressed in the literature that certain stages of wheat development, notably booting and heading, are more sensitive to moisture stress.

A field experiment was conducted with wheat to study the effect of full and deficit irrigation on crop yield and water-use efficiency in the semi-arid climate of Central Anatolia. The objectives of the study were (1) to evaluate the impact of full and deficit irrigation on wheat grain yield applied during different growing stages; and (2) to establish relationships between grain yield, quality and water-use efficiency.

2. Materials and methods

2.1. Experimental site

The present study was conducted on the experimental fields of Soil and Water Resources Research Institute (37°52′N, 32°30′E, and 1016 m above see level) of Konya, Turkey during the period 2009–2012.

A typical semiarid climate conditions is dominant in the region. Summers are hot and dry, and winters are cold and precipitated. Winter precipitations continue in spring but distributions exhibit significant variations from year to year. According to long-term averages, the hottest month is July and the coldest month is January.

Daily climate parameters were measured at a weather station located adjacent to the experimental site, and the annual average precipitation, temperature, relative humidity, wind speed, and evaporation were respectively measured as 318 mm, 11.9 °C, 56.8%, 2.2 m s^{-1}, and 1347 mm.

Data related to the soil properties of the experimental site are summarized in Table 1. The soils were classified as alluvials of clay texture with 205 mm of available-water holding capacity and a soil depth of 90 cm. The soils were determined to be poor in organic matter (0.22–0.60%) and available phosphorus (7.88–19.00 mg kg^{-1} P_2O_5), and rich in available potassium (496–592 mg kg^{-1} K_2O). Irrigation water used was classified as C_2S_1 with a medium salt and low sodium content.

2.2. Experimental procedure

Soil was prepared using standard tillage equipment for planting. A combined driller that facilitated a concurrent application of fertilizer and seeds was used. Konya 2002 drought sensitive and cold tolerant wheat cultivar (BDIAR, 2015) was grown as a test plant in the experiment. Wheat seeds were sown on 12 November 2009 and 16 November 2011, with a seed rate of 180 kg per hectare at 5 cm soil depth and 13.5 cm row spacing. A compound fertilizer (20-20-0) was applied (80 kg ha^{-1} N and 80 kg ha^{-1} P_2O_5) at planting. The rest of N fertilizer was applied during tillering at a rate of 80 kg ha^{-1}. All treatment plots received the same amount of total fertilizer. A total of 80 kg ha^{-1} P_2O_5 and 160 kg ha^{-1} N were applied as fertilizers.

Each experimental plot was 8.00 m × 2.70 m (20 rows per plot) and had a total area of 21.60 m^2 at sowing and 6.00 m × 1.20 m (7.20 m^2) at harvest. Sufficient distance was left between the plots and blocks to prevent horizontal water flows. Experiments were conducted using randomized complete block design with three replications. Herbicides were used in the early spring for weed control.

Harvesting was performed using a parcel harvester on 13 July 2010 and on 15 July 2012. The grain moisture content was determined for each treatment right after harvesting. Since the moisture content was lower than 12%, a moisture correction was not performed on the yield values. Also, wheat plants were harvested at ground level from 1 m^2 of each plot to find out biomass yields.

2.3. Treatments

Irrigation treatments were established based on different growth stages of wheat—namely, the stem elongation, heading and milk stages. There were 22 irrigation treatments, including full irrigation and without irrigation (rainfed). The treatments and irrigation levels are provided in Table 2.

2.4. Irrigation system

Drip irrigation was used in the irrigation of experimental plots. The control unit of the irrigation-system was composed of hydrocyclone, fertilizer tank, mesh filter, pressure gauges, and valves. Filtrated water was delivered to the experimental site using 75 mm PE pipes and was distributed to the plots via 50 mm PE manifold lines. Inside the plots, 16 mm PE laterals were used. Lateral spacing was 40 cm. Drippers used in the irrigation system were set 33 cm apart and had a flow rate of 2.4 L h^{-1} at 1.0 atm. pressure, and the selection of the drippers were based on soil characteristics described by Keller and Bliesner (1990). For better germination and homogeneous crop cover, all plots were irrigated after sowing using sprinkler system, equal water amounts being applied to each plot. The drip irrigation system was installed in the plots before the tillering period.