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Research Paper

Yield, water and nitrogen use efficiencies of sprinkler irrigated wheat grown under different irrigation and nitrogen levels in an arid region

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ABSTRACT

A major challenge in crop production is to achieve the goal of increasing both yield and resource use efficiency. Irrigation water and nitrogen (N) are scarce and expensive resources constraining wheat production in arid regions. There is limited information on how irrigation and N supply can be simultaneously manipulated to achieve higher yield, water productivity (WP), and nitrogen use efficiency (NUE) of wheat in arid regions. A two-year field experiment was conducted to investigate the effects of irrigation and N rates on yield, WP and NUE of wheat in a hot, arid environment at Bikaner, India. The experimental treatments comprised of six irrigation [100% (ETm; full evapotranspiration), 90% (ETd1), 80% (ETd2), 70% (ETd3), 60% (ETd4), and 50% (ETd5) of ETc (crop evapotranspiration)] levels, and four N [0 (N0), 40 (N40), 80 (N80), and 120 (N120) kg ha^{-1}] rates. Moderate deficit irrigation (ETd2) had greatest WP and caused a 17% reduction in water consumption with only a 5% reduction in yield compared to full irrigation (ETm). The N application improved yield and WP. The NUE declined with a reduction in water application and an increase in N rates. The yield and WP response to N rates modified with irrigation levels.The significant increase in grain yield was recorded with N120 at ETm and ETd1, with N80 at ETd2 and ETd3, and with N40 at ETd4 and ETd5 irrigation levels. The significant increase in WP was recorded with N80 at ETm, ETd1, ETd2 and ETd3, and with N40 at ETd4 and ETd5 irrigation levels. The results suggested that moderate deficit irrigation (ETd2) along with 120 kg N ha^{-1} could ensure satisfactory grain yield and WP of wheat in arid regions. The study also indicated that the adoption of an appropriate deficit irrigation and N rate combination can be an effective means to reduce non-beneficial water consumption, achieve higher yield, and improve WP and NUE for wheat in an arid environment.

1. Introduction

Globally, agriculture uses almost 70% of all fresh water withdrawals for irrigation (Shen et al., 2008). Irrigated agriculture produces about 40% of all food from about 17% of the cropped land area (Fereres and Connor, 2004). Due to continued population growth, urbanization, and industrialization, agriculture will increasingly compete with other sectors for fresh water (Godfray et al., 2010; Tilman et al., 2011). The global demand for food crops is expected to approximately double by 2050 (Tilman et al., 2011). Therefore, crop production will need to increase to meet the projected demand for food, but the portion of fresh water available to agriculture is decreasing (Cai and Rosegrant, 2003). This highlights the challenges agriculture is faced with the need to grow more food with less water (Godfray et al., 2010). Hence, sustainable methods to increase crop water productivity (WP) are gaining importance, particularly in arid and semi-arid regions, where water remains a major production constraint.

Wheat (*Triticum aestivum* L.) is one of the most important crops, providing over 20% of the calories consumed by the world's population (Braun et al., 2010). It is an important crop in irrigated perimeters of the arid region of India (Gajja et al., 2008; Rathore et al., 2010), where it is grown during November to April. The precipitation ranges from 30 to 50 mm, while the average evaporation is 800–1000 mm during the wheat growing season. To achieve high yield, farmers in this region pump groundwater to irrigate wheat to offset the evapotranspiration (ET) deficit. The excessive exploitation of groundwater (which constitutes 52.3% share in the total

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irrigated area in northwestern Rajasthan) for irrigation is depleting at an alarming rate (Rathore, 2005), and is posing a serious threat for sustainable crop production in the region. Therefore, it is essential to improve WP of wheat production in this region. Within this context, deficit irrigation (DI), defined as the application of irrigation water below the full crop ET, is an important strategy to increase the efficiency of water use, particularly in dry regions (English et al., 2002; Geerts and Raes, 2009).

Numerous studies have assessed the effects of DI on wheat growth, yield, and WP (Ali et al., 2007; Pradhan et al., 2014; Rao et al., 2013; Wang et al., 2012). Earlier research has shown that DI significantly improved WP by 11–40% (Rao et al., 2013; Wang et al., 2012; Zhang et al., 2006) compared to full irrigation (FI) in the wheat crop. Zhang (2003) compared the effects of DI on WP of wheat for three locations, representing different climatic conditions (Syria, North China Plain and Oregon, USA). The author concluded that the level of water application at the maximum WP differs considerably for three locations, and the optimum DI varies considerably among locations having different pedo-climatic and crop management practices. Therefore, the implementation of DI requires the quantification of crop response to water limitation under given pedo-climatic conditions of specific region (Geerts and Raes, 2009).

Besides water, nutrient is another key factor determining the growth and yield of crops (Li et al., 2009). Nitrogen (N) is the key element in plant nutrition and strongly influences crop yield. The worldwide recovery of N fertilizer in wheat is low, i.e. approximately 30–50% (Spiertz, 2010). The poor recovery of applied N increases input cost to farmers and environmental problems. Therefore, improving nitrogen-use efficiency (NUE) is an important challenge to reduce input cost to farmers, and environmental impact of N losses while maintaining crop yield. It has been reported that, interaction and complementary activities of water and N are the main factors that affect yield and resource (water and N) use efficiency of crop production (Eck, 1988; Pandey et al., 2001; Pradhan et al., 2014). Eck (1988) evaluated the effects of irrigation and N application rates on WP of winter wheat, and reported that WP increased with increments of N through 140 kg ha^{-1} on non-stressed treatment, and through 70 kg ha^{-1} on stressed during head filling and grain filling stages, but applied N did not affect WP on stressed throughout crop growing season. In contrast, Pradhan et al. (2014) investigated effects of four levels of irrigation (rainfed, irrigation replenishes to 30, 60 and 100% moisture deficit from field capacity) and N (0, 30, 60 and 120 kg N ha^{-1}) on WP and NUE of wheat in semi-arid region of India. They reported that the WP of wheat increased up to the application of 120 kg N ha^{-1} in all irrigation regimes. They observed greatest WP and NUE without any significant reduction in crop yield with application of 120 kg N ha^{-1} and irrigation to replenish 60% soil moisture depletion to field capacity.

It is clear, therefore, the understanding of the interactive effects of water and N availability, along with the crop's ability to efficiently use these resources (expressed by WP and NUE, respectively) are of crucial importance for improving WP and NUE while maintaining high yield of wheat in hot, arid region having sandy soils, which are vulnerable to leaching of water and soluble nutrients. The objective of this work was to study the interaction between water and N applied at different levels on growth, yield components, and yield of wheat as well as to analyze the efficiency of water and N used by the crop in an arid environment. Such a study would provide useful information to wheat production, achieving a higher grain yield and high resource use efficiency, and give insight into understanding the mechanism underlying the interaction between water and N on wheat growth and yield. Furthermore, this knowledge will aid in the development of concurrent management strategies for irrigation and N application amounts in wheat for the hot arid region.

2. Materials and methods

2.1. Experimental site

Field experiments were conducted at the research farm of Regional Research Station, Bikaner of the Central Arid Zone Research Institute, Rajasthan, India (28° 4′N; 74° 3′E, 238.3 m altitude) during the wheat growing season (October–March) of 2011–12 and 2012–13. The climate of the site is a hot arid having 286 mm mean annual precipitation, the most of which is received during July–September. The air temperatures, precipitations and evaporations during the wheat growing seasons across the two study years measured at weather stations located 800 m away from the site are shown in Fig. 1. The soil (0–20 cm layer) of the experimental site was a sandy loam (Typic Torripssamentes, US classification) that contained 1.2 g kg^{-1} organic carbon (the Walkley–Black method), 4.6 mg kg^{-1} (Olsen) available phosphorus, 105.3 mg kg^{-1} (1 N NH_4 acetate) available potassium, 8.4 pH (soil/H_2O, 1:2.5) and 841 g kg^{-1} sand (2000–50 μm), 46 silt g kg^{-1} (50–2 μm) and 113 g kg^{-1} clay (<2 μm).The important physico-chemical properties of soil layer up to 100 cm are shown in Table 1.

2.2. Experimental design and treatments

The experiment was a 6 × 4 (six irrigation levels and 4 N rates) factorial design with 24-treatment combinations. The treatments laid out in a split-plot design with irrigation in main plots (10 m wide and 37 m long, 370 m^2), and N rates in sub-plots (10 m wide and 7 m long, 70 m^2). The treatments comprised six levels of irrigation based on crop evapotranspiration (ETc) viz. 100% (ETm, full evapotranspiration), 90% (ETd1), 80% (ETd2), 70% (ETd3), 60% (ETd4) and 50% (ETd5) of ETc. The N rate treatments consisted four levels viz. 0, 40, 80 and 120 kg N ha^{-1} (designated as N0, N40, N80 and N120, respectively). The treatments were replicated three times.

The experimental site was 231 m × 37 m field with a replication size of 75 m × 37 m. Sprinkler line was laid out in each main plot which offered irrigation to four sub-plots. The irrigation was applied through 32 mm PVC pipe line with a total of 24 mini-sprinklers (double nozzle, 2.5 mm × 1.8 mm size having discharge of 7.5 lpm at 2.5 kg cm^{-2} pressure; M/S Jain Irrigation Ltd; spaced at 10 m interval). A flow-meter was installed at the head of lateral pipe at each main plot to measure the applied water. Sprinkler irrigations were performed in the morning provided wind speed was <2 m s^{-1}. Pan evaporation and rainfall recorded from India Meteorological Department Class A Meteorological observatory located about 800 m away from the experimental site. The daily crop evapotranspiration requirement (ETc) was estimated using the equation:

$$ETc = Epan \times Kp \times Kc \quad (1)$$

where Epan, pan evaporation (mm); K_P, pan coefficient (0.75); K_C, crop coefficient, which varies for different growth stages of the crop as per FAO 56 (Allen et al., 1998). A uniform pre-sowing irrigation of 70 mm was applied to all plots. Subsequent irrigations were applied after ≥45 mm of ETc. This resulted in irrigations every 8–10 days. The irrigation water requirement to be given through sprinkler irrigation was calculated as ETc × irrigation efficiency (80%) and a ready reckoner was prepared and irrigation was given as per irrigation treatments. N was applied through urea (46% N) in two splits, *i.e.*, 50% at sowing and the remaining 50% with the first irrigation.