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# Water use and soil nitrate nitrogen changes under supplemental irrigation with nitrogen application rate in wheat field

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ABSTRACT

Excessive or improper nitrogen (N) application rates and water shortages negatively affect crop production and thereby food security, particularly for winter wheat production in the Huang-Huai-Hai Plain of China. Therefore, it is highly important to study effects of N application rates under supplemental irrigation on water use and changes in soil nitrate–N ($NO_3$—N) content in winter wheat in this region. In a field experiment, we tested four N application rates: 0 (N0), 180 (N1), 210 (N2) and 240 (N3) kg N ha$^{-1}$. Under different N treatments, supplemental irrigation raised soil water content in the 0–140 cm profile to 70% field capacity (FC) at both jointing and anthesis in the period from 2012 to 2013 and 70% FC at jointing and 65% FC at anthesis in the period from 2013 to 2014. The total amount of supplemental irrigation for N2 was lower than that for N3. The highest crop evapotranspiration, water consumption after anthesis and soil water consumption were observed in N2. Soil water consumption in N2 in 60–140 cm soil layers was significantly greater than in other treatments. The net photosynthesis rate, transpiration rate and stomatal conductance of flag leaves from N2 were greater than those from other treatments from 7 to 21 days after anthesis. But $NO_3$—N content of N2 was significantly lower than that of N3 in 0–120 cm soil layers at anthesis and in 60–160 cm soil layers at maturity. The highest grain yields of 8923.2 and 9064.9 kg ha$^{-1}$ were attained in N2 with a high water use efficiency of 20.9 and 18.8 kg ha$^{-1}$ mm$^{-1}$ in periods from 2012 to 2013 and 2013 to 2014, respectively. These results indicate that the optimal N application rate was 210 kg N ha$^{-1}$ under supplemental irrigation.



## 1. Introduction

The Huang-Huai-Hai Plain is one of the most important food production bases in China, where more than 60% of wheat is produced and the irrigation area occupies about 70% of total wheat planting area (National Bureau of Statistics of China, 2013). However, water resources are scarce and nitrogen (N) fertiliser has been excessively applied in this area (Gheysari et al., 2009; Li et al., 2008). Water shortages and high N fertiliser inputs in the winter wheat growth season have seriously threatened the sustainable development of agriculture in recent years (Guo et al., 2010; Zhang et al., 2010). Therefore, water-saving cultivation techniques and N application regimens for winter wheat are commonly used in this area (Wang et al., 2014; Zhang et al., 2013).

Nitrogen is an essential plant nutrient that affects productivity, crop water use and water use efficiency (WUE) of wheat (Cossani et al., 2010; Devadas et al., 2014; Garnett et al., 2009; Morell et al., 2011). For example, Behera and Panda (2009) reported that the crop evapotranspiration (ET) in the 80 kg N ha$^{-1}$ treatment was higher by 22 mm from 2002 to 2003, 28.3 mm from 2003 to 2004 and 37.3 mm from 2004 to 2005 than that in the 0 kg N ha$^{-1}$ treatment under 40% maximum allowable depletion of available soil water. Moreover, the response of crops to N fertilisation is dependent on soil water status, amount and frequency of precipitation during the growing period of crops, more than amount and timing of N applications (Latiri-Souki et al., 1998; Tilling et al., 2007). In the semiarid Loess Plateau in China, Guo et al. (2012) reported that the optimal N fertilisation rates in dry, normal and wet years were 45, 135 and 180 kg ha$^{-1}$, respectively, in a rain-fed winter wheat cropping system. Di Paolo and Rinaldi (2008) indicated that an appropriate soil water level had a positive effect on N availability and the simultaneous uptake of water and N. Guo et al. (2014) and Li et al. (2012) noted that supplemental irrigation significantly affected soil moisture content. Therefore, it is necessary to study the effect of the

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optimal N fertilisation rate under supplemental irrigation on water use and wheat yield in this area.

The levels of N fertiliser and irrigation amounts are the main factors that influence the nitrate–N ($NO_3$—N) content in soil. Several studies showed that $NO_3$—N losses decreased with reductions in fertiliser application rates (Moriasi et al., 2013; Randall and Vetsch, 2003). For example, $NO_3$—N losses were decreased by 67% when the N application rate decreased by 50% (Moriasi et al., 2013). Yang et al. (2014) reported that nitrate leaching mainly occurred after irrigation, and that $NO_3$—N leaching increased as more irrigation water was applied (Gheysari et al., 2009; Vázquez et al., 2006). Therefore, to reduce soil $NO_3$—N leaching, it is necessary to optimise N applications under supplemental irrigation by considering soil water content (SWC) in the 0–140 cm soil layers.

We applied four N application rates (0, 180, 210 and 240 kg N $ha^{-1}$) to field soils under SWC irrigated to 70% field capacity (FC) at both jointing and anthesis from 2012 to 2013 and 70% FC at jointing and 65% FC at anthesis from 2013 to 2014. The objectives of the present study were as follows: (1) to clarify the effect of N fertilisation rate on the irrigation amount at the jointing and anthesis stages and water consumption amount of crop at different growth period; (2) to evaluate the dynamics of soil water consumption and soil $NO_3$—N content in the 0–200 cm soil layers and (3) to determine the optimal N fertilisation rate under supplemental irrigation for higher grain yield and WUE of winter wheat.

## 2. Materials and methods

### 2.1. Site descriptions

The experiment was performed during the winter wheat growing seasons from 2012 to 2014 at Shandong Agricultural University Experimental Station, which is located in the centre of China's Huang-Huai-Hai Plain (36°09′ N, 117°09′ E). The soil type in the experimental field was silt loam with 14.6 g $kg^{-1}$ soil organic matter, 102.1 mg $kg^{-1}$ hydrolysable N, 39.4 mg $kg^{-1}$ available phosphorous, 88.4 mg $kg^{-1}$ available potassium and 1.0 g $kg^{-1}$ total N in the 0–20 cm soil layers. The soil bulk density and field capacity of the soil in the 0–140 cm soil layers are shown in Table 1. Precipitation during the winter wheat growing seasons is shown in Fig. 1.

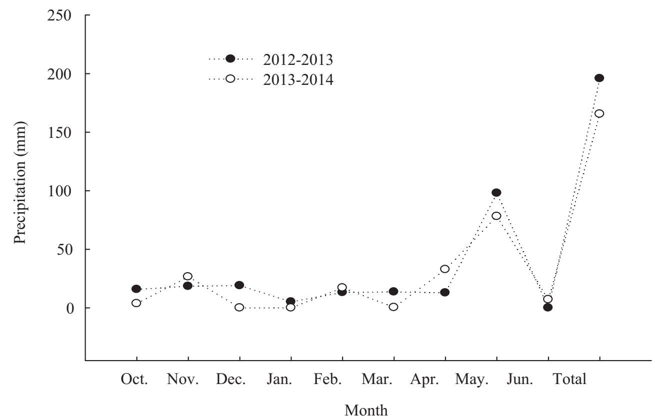


**Fig. 1.** Precipitation in the growth seasons of winter wheat in 2012–2013 and 2013–2014.

### 2.2. Experimental design

The four N application rates were 0 (N0), 180 (N1), 210 (N2) and 240 (N3) kg N $ha^{-1}$. Half of the N application rate was applied to the experimental plots before sowing and the remaining N fertiliser was applied by ditching at the jointing stage. Supplemental irrigation for each N application treatment (Table 2) was applied at the jointing/Z31 (first detected node) and anthesis/Z61 (beginning of anthesis) stages (Zadoks et al., 1974). Each experimental plot was 2 m × 10 m, with three replicates in a randomised design. Between adjacent irrigation plots, a 2 m wide non-irrigated zone was maintained to minimise the effect of adjacent plots. Water was sprayed evenly onto the experimental plots under pressure. A flow metre was used to measure the amount of water applied.

### 2.3. Crop management

The wheat cultivar 'Jimai 20' which has high yield and strong gluten potential was used for the experiment. Before sowing, 112.5 kg $K_2O$ $ha^{-1}$, 112.5 kg $P_2O_5$ $ha^{-1}$. Wheat seeds were sown at a density of 180 plants $m^{-2}$ on 7 October 2012 and 7 October 2013. Wheat was harvested on 8 June 2013 and 4 June 2014. Other management practices, such as pest control and tilling practices, were

**Table 1**
The soil field capacity and bulk density of the soil in the 0–140 cm soil layer in the experimental plots.

| Soil layer (cm) | 0–20 | 20–40 | 40–60 | 60–80 | 80–100 | 100–120 | 120–140 |
|---|---|---|---|---|---|---|---|
| Field capacity (%) | 28.49 | 27.08 | 26.41 | 23.4 | 23.24 | 24.4 | 25.79 |
| Bulk density (g $cm^{-3}$) | 1.44 | 1.51 | 1.54 | 1.56 | 1.58 | 1.58 | 1.58 |

**Table 2**
The actual relative soil water content before and after supplemental irrigation (θar, θar′ %, field water capacity) in the 0–140 cm soil layer for treatments (N0, N1, N2, N3) at the jointing and anthesis stages in 2012–2013 and 2013–2014.

| Years | Treatment | Jointing | | | Anthesis | | | Total SI |
|---|---|---|---|---|---|---|---|---|
| | | θar | θar′ | SI | θar | θar′ | SI | |
| 2012–2013 | N0 | 65.5a | 69.3 | 24.2d | 54.4b | 70.0 | 83.6a | 107.7c |
| | N1 | 62.1b | 69.3 | 42.2c | 55.8b | 69.8 | 76.4a | 118.5b |
| | N2 | 59.9c | 70.7 | 54.2b | 55.1b | 69.0 | 80.0a | 134.2a |
| | N3 | 57.6d | 70.7 | 66.3a | 57.0a | 70.7 | 69.8b | 136.1a |
| 2013–2014 | N0 | 60.4a | 69.9 | 53.0d | 56.3b | 65.7 | 47.9a | 100.9c |
| | N1 | 59.0b | 69.8 | 60.6c | 57.5a | 64.9 | 41.4b | 102.0c |
| | N2 | 53.8c | 70.5 | 89.5b | 56.2b | 65.6 | 48.4a | 138.0b |
| | N3 | 52.4d | 68.9 | 97.1a | 56.3b | 64.4 | 47.9a | 145.0a |

The amount of supplemental irrigation (SI, mm) is also indicated.
Mean values within columns at the same growing season of wheat followed by the different letters differ significantly ($P < 0.05$).