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# Effects of drip system uniformity and nitrogen application rate on yield and nitrogen balance of spring maize in the North China Plain

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ABSTRACT

The effects of drip system uniformity and nitrogen application rate on spring maize growth, nitrogen uptake, yield, yield components, nitrogen agronomic efficiency, and apparent nitrogen loss were investigated through field experiments to modify the current design and evaluation standards for drip system uniformity. The experiments were conducted in the North China Plain during two growing seasons of spring maize (*Zea mays* L.) in 2011 and 2012 using 27 experimental plots of 30 m long and 3 m wide. Three Christiansen uniformity coefficients (*CU*) of 59, 80, and 97% and three levels of nitrogen applied at 0, 120, and 210 kg $ha^{-1}$ were tested. The results demonstrated that the drip system uniformity had an insignificant effect on plant growth, plant nitrogen uptake, yield, yield components, nitrogen agronomic efficiency, and apparent nitrogen loss at a significance level of $p < 0.05$. The influence of nitrogen application rate on plant growth, plant nitrogen uptake, and yield was related to the initial nitrogen content in the soil. High nitrogen soil fertility reduced the effect of nitrogen fertilizer on crop yield. The apparent nitrogen loss increased significantly with nitrogen application rate whereas the difference of yields between the treatments with nitrogen applied at 120 and 210 kg $ha^{-1}$ did not reach a statistical significance. In the subhumid region of the North China Plain where irrigation only accounts for 21–23% of the precipitation during the growing season of maize, a drip system uniformity that is lower than the values recommended by the current standards might be used to reduce the installation and operation costs of drip irrigation systems. Using a nitrogen application rate that is lower than the conventional values (e.g., 210 kg $ha^{-1}$) is a promising practice to reduce nitrogen losses while maintaining an acceptably high level of yield.

## 1. Introduction

Nitrogen (N) fertilizer application has proved to be an effective approach for improving grain yields in intensively managed agriculture. However, excessive application and unreasonable management of N could lead to low N efficiency and high fertilizer losses through runoff, leaching, denitrification, and volatilization (Raun and Johnson, 1999; Xing and Zhu, 2000; Shi et al., 2012), resulting in a series of environmental problems and an increase of production costs. The North China Plain, producing 21.6% of the grain yields in China, plays an important role in guaranteeing the national food security. An extremely low N fertilizer recovery efficiency has been reported in this region (Cui et al., 2008). Efficient N utilization is therefore becoming a more and more concerned topic for environmental and economic reasons.

Drip fertigation has been recognized as a more efficient method to improve N use efficiency compared to the conventional methods (Bar-Yosef, 1999). However, it is not necessarily a method of reducing the risk of nitrate leaching unless environmentally sound irrigation and N application practices are implemented (Gärdenäs et al., 2005; Ajdary et al., 2007; Zotarelli et al., 2008). Drip system uniformity is an important parameter in the design, maintenance, and management of drip irrigation systems (Barragan et al., 2010). A commercial installation of drip irrigation system with low system uniformity is bound to produce a nonuniform fertilizer distribution within the irrigation unit (Li et al., 2007) because the in-season fertilization is completed through the drip irrigation system by fertigation. Either over- or under-application of water and fertilizers in partial zones of the unit caused by the system nonuniformity possibly imposes negative impacts on crop growth. Moreover, a lower uniformity may lead to nitrate leaching, causing environmental hazard. However, the initial installation costs and maintenance costs of systems usually increase with

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**Table 1**
Particle size distribution, texture, bulk density, field capacity, and soil water content at 1500 kPa suction of the experimental field.

| Depth (cm) | Particle size distribution (%) | | | Texture | Soil bulk density (g $cm^{-3}$) | Field capacity ($cm^3$ $cm^{-3}$) | Soil water content at 1500 kPa ($cm^3$ $cm^{-3}$) |
|---|---|---|---|---|---|---|---|
| | Clay | Silt | Sand | | | | |
| 0–20 | 13.7 | 52.4 | 33.9 | Silt loam | 1.37 | 0.33 | 0.10 |
| 20–60 | 13.5 | 54.1 | 32.4 | Silt loam | 1.41 | 0.33 | 0.09 |
| 60–100 | 16.5 | 52.8 | 30.7 | Silt loam | 1.46 | 0.33 | 0.10 |

uniformity values (Wilde et al., 2009). Several design and evaluation standards of drip system uniformity have been developed in different countries (e.g., ASAE Standards, 1988; Chinese Standard, 1995; ASABE Standards, 2003). ASABE Standard EP405.1 (2003) recommends a design emission uniformity (*EU*) of 70%–95% depending on the source (point or line source), crop, emitter spacing, and field slope. Chinese National Standard SL 103-1995 (1995) suggests a design Christiansen uniformity coefficient (*CU*) of greater than 80%. There has been considerable interest in studying the effect of system uniformity on crop yields in recent several decades. Stern and Bresler (1983) concluded that a more uniform corn yield than the water applied could be expected due to the redistribution of non-uniformly applied sprinkler water in the soil. Mateos et al. (1997) indicated that there were no significant differences in cotton yield whether the irrigation uniformity (Wilkox and Swailes' uniformity coefficient) was 80% or 52%. In a five year study conducted in the Texas High Plains, significant difference in cotton yield was not observed among subsurface drip irrigation treatments at flow variations ($q_{\text{var}}$) of 5%, 15%, and 27% (Bordovsky and Porter, 2008). The experiments conducted in a greenhouse in a subhumid region demonstrated that the effect of drip system uniformity on the yield of Chinese cabbage head was insignificant when the Christiansen uniformity coefficient (*CU*) varied from 57 to 96% (Zhao et al., 2012). These experimental results have indicated that a uniformity that is lower than the values recommended by current standards has minor influence on crop yield. However, this result may be needed to be confirmed on different crops under various climatic conditions. Moreover, no study has been found on the effect of drip system uniformity on the N use efficiency and N balance in the literature. Further research on this aspect under a wide range of system uniformities would be helpful to modify the current evaluation standards of drip system uniformity from an environmental and economic view.

Nitrogen application rate is an additional factor that affects nitrate use efficiency in modern agricultural, especially in the North China Plain where excessive N application has been used as a common practice to enhance the crop yields (Ju et al., 2009; Cui et al., 2010). However, many researchers have reported that excessive N application could not significantly increase crop yields but increased the N loss considerably (Matson et al., 1997; Ju et al., 2009; Hou et al., 2012; Shi et al., 2012). The optimal N application rate was also critical for the efficient utilization of N. The objectives of the present study were to investigate the effects of drip system uniformity and N application rate on plant growth, N uptake, yield, N use efficiency, and N balance of spring maize in the North China Plain and to provide recommendations for modifying the design criteria for microirrigation systems through field experiments.

## 2. Materials and methods

### 2.1. Experimental field

Field experiments were conducted at the Experimental Station of the National Center of Efficient Irrigation Engineering and Technology Research, Beijing (39°39′N, 116°15′E, and 40.1 m above the sea level) in the North China Plain. The region has a warm and subhumid continental monsoon climate with an annual mean temperature of 11.6 °C and an annual mean precipitation of 556 mm with more than 70% occurs between July and September. The particle size distribution of the soil in the experimental field was measured using a laser method (Mastersizer 2000, Malevern Instruments, Ltd., Malvern, UK), and the texture was classified as silt loam (Shirazi and Boersma, 1984) (Table 1). The bulk densities at different depths were measured by a 100-$cm^3$ ring. The field capacity was measured by an in situ test and the soil water content at wilting point were determined at 1500 kPa suction using a centrifugal method (CR 21GII, Hitachi, Japan) (Table 1). An automated wireless weather station was installed 50 m from the experimental field to monitor precipitation, air temperature, humidity, solar radiation and wind speed every 30 min.

### 2.2. Experimental design and treatments

Spring maize (*Zea mays* L.), a water- and N-sensitive crop (Di Paolo and Rinaldi, 2008), was selected as the experimental crop. The experiments were conducted in the 2011 and 2012 growing seasons. In the 2011 and 2012 experiments, spring maize was seeded on May 3 and May 1, respectively, with a row spacing of 50 cm. During both seasons, thinning operation was carried out on the 25th day after planting at a planting spacing of 40 cm, resulting in a population density of 50,000 plants per hectare. Spring maize was harvested on August 30 in the 2011 experiments and on August 27 in the 2012 experiments.

In the experiments, two factors were considered: drip system uniformity and N application rate. The Christiansen uniformity coefficient (*CU*) (Christiansen, 1941) was used to quantify the uniformity of the emitter discharge rate in each experimental plot.

$$CU = 100 \times \left(1 - \frac{\sum_{i=1}^{N} \left|x_i - \bar{x}\right|}{N\bar{x}}\right) \tag{1}$$

where $x_i$ is the emitter discharge rate (L $h^{-1}$), $\bar{x}$ is the mean of $x_i$, and *N* is the number of samples. For both years, three designed *CU* levels of 60% (referred to as low uniformity, C1), 80% (referred to as medium uniformity, C2), and above 95% (referred to as high uniformity, C3) and three N application rates of 0, 120, and 210 kg N $ha^{-1}$ (referred to as low N application level N0, medium N application level N1, and high N application level N2, respectively) were evaluated. The high N application rate approximated the conventional N usage in the experimental area (Zhao et al., 2009). This experimental design resulted in nine treatments: C1N0, C2N0, C3N0, C1N1, C2N1, C3N1, C1N2, C2N2, and C3N2. The experiments were arranged as completely randomized design with three replications. In total, 27 experimental plots of 30 m long and 3 m wide were created. A 60 cm buffer zone between adjacent plots reduced the likelihood of lateral exchange of water between plots and allowed for access to each experimental plot.

For each plot, three driplines were installed along the median of two adjacent spring maize rows, and the two rows were irrigated by one dripline (Fig. 1). These installations resulted in a lateral spacing of 1 m. The uniformity of a drip system in field generally depends on the hydraulic design, manufacturer's variation, temperature effect,