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Evaluation of optimal nitrogen rate for corn production under mulched drip fertigation and economic benefits

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ABSTRACT

Field experiments were conducted in Chifeng of Inner Mongolia, China, in 2015 and 2016 to explore the potential of mulched drip fertigation (MDF) to improve yield and nitrogen use efficiency (*NUE*) for corn. Six nitrogen (N) application levels under MDF were set: 0, 140, 190, 240, 290 and 340 kg ha^{-1} (i.e., MDFN0, MDFN140, MDFN190, MDFN240, MDFN290 and MDFN340), and a treatment under conventional furrow fertilization (CFN340) was added as control. The dynamic changes in soil nitrate N (NO_3–N) residual and plant N uptake (*NU*) during corn growing season, the responses of *NUE* to N fertilizer supply and corresponding economic benefits were analyzed in this study. These tasks aimed to establish the optimal N rate under MDF, in particular to compare the widely used N rate of 340 kg ha^{-1} by the local producers of high yielding corn. Based on the results, the following conclusions could be drawn: (1) N rate significantly influenced the soil NO_3–N residual and plant *NU*. When N rate was less than 190 kg ha^{-1}, the soil NO_3–N residual decreased each year. The soil NO_3–N residual maintained balance between years when N rate measured 240 kg ha^{-1}. By contrast, when N rate was higher than 290 kg ha^{-1}, the soil NO_3–N residual increased each year, furthermore, the NO_3–N residual of 80–180 cm soil in harvest season under MDFN290 and MDFN340 increased by 26.9% and 48.4%, respectively, in comparison with that in MDFN240. When N rate ranged within 0–240 kg ha^{-1}, each 50 kg ha^{-1} increase in N rate caused a 16.7% average improvement in total *NU* of corn. However, the increase rate of *NU* dropped until negative growth appeared at increased amount of N fertilizer. (2) All corn yields, net outputs, and N recovery efficiencies (*NREs*) tended to increase initially and then decrease with N rate increasing, and the optimal value of each index was obtained in MDFN240. The N fertilizer amount of MDFN240 decreased by 29.4% in comparison with that in MDFN340, but the yield, net output and *NRE* increased by 8.3%, 13.4% and 35.1%, respectively. Moreover, the MDFN240 treatment decreased the NO_3–N residual of 80–180 cm soil by 49.2%. However, this increased the yield, net output and N partial productivity efficiency by 11.4%, 22.1% and 58.3%, respectively, in comparison with those of CFN340. (3) Based on the consideration of environment and optimal economic yield (15.6 Mg ha^{-1}) computed by nitrogenous fertilizer effect function model, the N rate of 240–253 kg ha^{-1} under MDF for corn was more reasonable with *NRE* potentially reaching 61.6%–62.2%. MDF showed obvious advantages in reducing N fertilizer and improving *NUE*.

1. Introduction

Nitrogen (N) is the most essential element in crop growth and development. Crop yield has significantly improved since the application of chemical N fertilizer in farmlands, and the contribution rate of N fertilizer to world grain yield even reached 30%–50% (Erisman et al., 2008). According to current trends, N fertilizer consumption will increase by 1.7 times in 2050 worldwide and may intensify climate warming, water eutrophication, soil pollution, and other major environmental issues (Tilman et al., 2001; Conley et al., 2009; Lu and Tian, 2013). Therefore, popularizing advanced fertilization technology and improving nitrogen use efficiency (*NUE*) are inevitable choices for the coordinated development of agriculture and environment.

Scientific N application should consider economic and environmental benefits (Lamm et al., 2004; Derby et al., 2005; Castellanos et al., 2013). The fertilizer is mainly absorbed by crops as nitrate N (NO_3–N) after it penetrates into soils. Insufficient supply of N fertilizer results in low yields, whereas excessive amounts generate high concentrations of NO_3–N residual in soil or considerable loss into the environment (Ju and Christie, 2011; Woli et al., 2016), soil water

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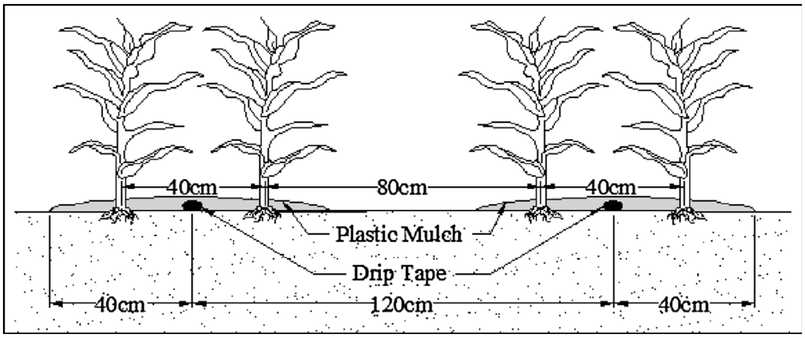

Fig. 1. The schematic diagram of cropping pattern and lateral layout of drip tapes under mulch for corn.

pollution, and decreased utilization rate of resources (Drecht et al., 2003; Pascual et al., 2013). Crop growth features a sensitive response mechanism to N fertilization. Crop colony structure, photosynthetic rate, and root activity are enhanced at increased N rate. However, excessive increase in N rate can lead to especially lush foliage, which is unfavorable to plant function (Nakamura et al., 2004; Wang et al., 2013; Liu et al., 2012). Optimal N rate should be established to ensure high yields and minimize the input and the loss of N fertilizer. Therefore, N uptake (*NU*) and soil NO_3–N residual distribution must be monitored during the crop growing season to achieve efficient N fertilizer management in farmlands.

Given that corn is a high-N consumption crop, an inappropriate N application scheme in conventional cultivation mainly presents excessive input amounts and unmatched N fertilizer supply with growth period, which leads to low *NUE*. In China, most farmlands still use conventional furrow fertilization (CF), N rates always reaches 300–450 kg ha^{-1} or higher, but *NUE* is only around 30% (Liu et al., 2003; Ju et al., 2009; Chen et al., 2012; Wang, 2008; Zhang et al., 2016; Huang et al., 2006). Some studies showed that N demands vary in each growth period of corn, and in-season fertilization with sufficient supply in later stages effectively ensured high yields (Sampathkumar and Pandian, 2010; Ciampitti and Vyn, 2011; Lv, 2012; Liu et al., 2014). Drip irrigation provides an effective way for timely–accurate irrigation and fertilization, and researchers conducted numerous studies on drip fertigation (DF), mainly focusing on water and N movement, N balance, and fertigation frequency (Lamm et al., 2001; Rajput and Patel, 2006; Li et al., 2010; Wang et al., 2014; Cetin et al., 2015; Farneselli et al., 2015). High-frequency DF for N promotes crop growth and *NU*; moreover, the low irrigation quota and direct delivery of water and fertilizer to crop roots under DF significantly reduces N loss from runoff and leaching; thus, the efficiency of water and nitrogen can be improved by using DF method (Kafkafi and Kant, 2005; Sampathkumar and Pandian, 2010; Fanish, 2013; Lamm, 2014).

In recent years, mulched drip irrigation for corn has been increasingly used in northern China. Film mulching can increase solar radiation absorption on the earth's surface to improve soil temperature and block migration of water vapor from deep to surface soil to reduce water evaporation (Wang et al., 2016). Film mulching can also effectively improve field microclimates around crops, contributing to root growth and plant function (Decoteau et al., 1989; Orzolek et al., 2003). The combination of mulching effect and soil moistening characteristics of drip irrigation changes soil water and heat conditions, affects nutrient transport and crop uptake, and reduces nutrient loss through volatilization and leaching in contrast to conventional drip irrigation (Vazquez et al., 2006; Lv, 2012; Li et al., 2017; Jayakumar et al., 2017). At present, few studies focus on the coordination mechanism of soil N fertility and plant growth for corn under mulched drip fertigation (MDF), and the optimal N fertilizer rate and *NUE* under MDF remain unclear.

In this study, field experiments were conducted to investigate the regulation of MDF to soil NO_3–N residual distribution and plant *NU* rules, and to analyze the response mechanism of corn yield to N fertilizer supply. Furthermore, this study aims to clarify the optimal N rate under MDF for corn based on economic benefits and provide theoretical basis for the establishment of N fertilizer management system with synchronous nutrient supply in root layer and corn growth demand.

2. Materials and methods

2.1. Site description

The field experiments were conducted in 2015–2016, Chifeng in Inner Mongolia, China (42°56′53″N, 119°4′20″E). The area has a semi-arid and continental monsoon climate with about 135–day frost-free period, the annual average rainfall and evaporation amounts are 350–450 and 1500–2300 mm, respectively.

The soil layer of 0–60 cm in the test site belongs to silt loam soil with a soil bulk density of 1.49 g cm^{-3} and a field water-holding rate of 34.45% (volume moisture content). The soil organic matter was 10.6 g kg^{-1}, the mass fraction for total N was 0.60 g kg^{-1}, the available potassium and phosphorus was 167 and 7.6 mg kg^{-1}, respectively.

2.2. Experimental design and field management

A multi-functional air-suction seeder was used to complete sowing, drip tapes laying and film mulching. The variety "Xianyu 335" was chosen in the test, and the planting date in 2 years was May 3 and May 2, respectively. The corn seeds were planted in alternate wide-narrow (80–40 cm) rows with a planting density of 83,330 plants ha^{-1}. The drip tape with wall thickness of 0.2 mm, drip flow of 1.38 L h^{-1} and dripper spacing of 40 cm was placed in the middle of narrow line. The corn cropping pattern and lateral layout of drip tapes under mulched drip irrigation is shown in Fig. 1.

The experiment used a completely randomized design for the variable factor of N rate. Six N application levels were set under MDF, namely, 0, 140, 190, 240, 290 and 340 kg ha^{-1} (i.e., MDFN0, MDFN140, MDFN190, MDFN240, MDFN290 and MDFN340), and a control treatment was added under conventional furrow fertilization (CFN340). The N rate of 340 kg ha^{-1} is widely applied in local high-yield corn fields. Each treatment was performed in triplicate, thus, 21 plots in total were arranged randomly. The size of each plot was 40 m × 6 m with 10 lines of corn planting.

The application amount of P_2O_5 and K_2O in all treatments was the same with 135 kg ha^{-1}. The N application scheme is shown in Table 1. The starter fertilizer, urea (N 46%), calcium superphosphate (P_2O_5 46%) and potassium sulfate (K_2O 52%), were applied to field by the seeder. All of the topdressing fertilizers, which involved urea (N 46%), monoammonium phosphate (P_2O_5 61%, N 12%) and potassium chloride (K_2O 62%), were soluble. The application percentage of the starter and topdressing fertilizer in MDF treatments are shown in Table 2. Whereas the P_2O_5 and K_2O in CFN340 were applied at planting, and the N were used for starter and topdressing fertilizers with a percentage of 6:4.