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Effects of application methods and urea rates on ammonia volatilization, yields and fine root biomass of alfalfa

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ABSTRACT

Minimizing nitrogen (N) losses via ammonia (NH_3) volatilization and maximizing yields with effective fertilization technologies in intensive cropping system is an essential part of sustainable agriculture. In 2016 and 2017, a study was conducted at an experimental station of China Agricultural University in Zhuozhou, Hebei Province, China, to quantify NH_3 volatilization by banding, surface broadcasting and center-pivot fertigation methods at three different N application rates (69.0, 48.3, 27.6 kg N hm^{-2}) by the calibrated Dräger-Tube method. The results showed that cumulative NH_3 volatilization losses were significantly affected ($P \leq 0.05$) by N application methods The air temperature and wind speed had positive correlations with NH_3 flux. The losses of banding, broadcasting, and fertigation were 1.08%, 1.34%, and 3.80% of total N application rates, respectively. The cumulative NH_3 volatilization losses increased, but the proportions of total N application rates decreased with increasing N application rates. The alfalfa yields of the 3rd and 4th cuttings were not significantly influenced ($P > 0.05$) by N application methods, while the fine root biomass was significantly affected ($P \leq 0.05$) by N application methods The season averaged NH_3 volatilization losses of each cutting was 1.73 kg N hm^{-2} under fertigation, which might not bring heavy burden to environment. Comparing to banding and broadcasting methods, fertigation caused a higher cumulative NH_3 losses, but led to a much higher yields and fine root biomass, with average values of 2.48 Mg hm^{-2} and 45.53 kg hm^{-2},respectively. Therefore, the fertigation method could be economically beneficial and environmentally sound in the North China Plain, where intensive cropping system is widely adopted.

1. Introduction

The North China Plain (NPC) is one of the major production region of alfalfa with a planting area of 1.1 million hm^2, which accounts for over 22% of the total planting area in China (China, 2015). However, low nitrogen use efficiency (NUE) and high labor cost are the main issues for alfalfa producers in this region. Excessive application rate of N fertilizer and outdated fertilization technologies are the main reasons. In recent years, the fertigation method using urea solution through center-pivot irrigation systems has increased rapidly in China (Li et al., 2017) because of its high irrigation efficiency, large coverage of irrigated area, high automation, and low labor cost (Valin et al., 2012).

Ammonia volatilization is one of major causes of the low NUE. Although the area of NCP was only 3.3% of the nation's total area, the total NH_3 volatilization from agriculture in NCP accounted for 27% of the total volatilization in China mainly because of its calcareous and alkaline soils (Zhang et al., 2010). Ammonia volatilization is mainly governed by the concentration of total ammoniacal nitrogen (NH_3^--N plus NH_4^+-N) in the soil solution and by the resistance to NH_3 movement from soil matrix (Sommer et al., 2004).These are decisively by the methods and amount of N applied (Ma et al., 2010). Increasing the amount of fertilizer N use can increase NH_3 loss because of direct increase in total ammoniacal nitrogen (Ma et al., 2010). Some studies reported that NH_3 volatilization increased linearly with N inputs, whereas other results found that NH_3 volatilization response to increasing N was exponential (Ma et al., 2010; Rochette et al., 2013). Thus, the relationship between NH_3 volatilization and N inputs cannot be consistent, as NH_3 volatilization varied greatly in fields with different agronomic practices as well as soil and climatic conditions. Conversely, it has been widely recognized that deep-placed urea can decrease NH_3 volatilization and improves NUE compared with surface broadcasting (Yao et al., 2017; Liu et al., 2015; Miah et al., 2016) since the resistance to the upward diffusion of ammoniacal N in the liquid and gaseous phases and the retention of NH_4^+-N on soil particles are increased when urea is placed at depth (Sommer et al., 2004). Nonetheless, the most conventional N application method is broadcasting in

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the NCP region because urea deep placement requires higher labor cost. Moreover, the lack of proper fertilizer deep applicator also limits the generalization of urea deep placement.

Roots are key organs to absorb and store nutrients and primary pathways for water uptake (Goins and Russelle, 1996). Root biomass of alfalfa is sometimes greater than above-ground biomass. Annual carbon and nutrient absorption by fine roots frequently equals or exceeds those extracted from leaves (Guo et al., 2010; Jackson et al., 1997). Urea deep placement in established alfalfa could mechanically damage the roots during the application, which leads to yield reduction and stand longevity (Misselbrook et al., 1996; Pfluke et al., 2011). The fertigation urea solution through existed irrigation system could not only avoid damaging the root system, but also improve the uniformity of fertilizer application. However, many studies found that the fertigation urea solution would generate more NH_3 volatilization than that of broadcasting and deep-placed methods (Misselbrook et al., 2004; Safley et al., 1992; Sharpe and Harper, 1997). Therefore, it is necessary to determine the most suitable N application method with the optimal application rate based on yield, fine root biomass, and NH_3 losses.

The objectives of this field study were to: (1) quantify NH_3 volatilization losses of different application methods and application rates, and (2) investigate the effects of application methods on the yields and fine root biomass of alfalfa.

2. Materials and methods

2.1. Experimental site description

This research was conducted from June to September (the 3rd and 4th cuttings of alfalfa) in 2016 and 2017 at China Agricultural University experimental station. The station (39°37′N, 115°51′E) is located in the region of North China Plain in Zhuozhou, Hebei, China. The climate is a typical temperate continental semi-humid monsoon with a summer precipitation pattern. Annual precipitation in the field ranges from 550 to 650 mm, 50%-75% of which falls between July and August. The soil type of the topsoil layer (0–30 cm) are sandy loam with very low organic matter content (0.8 g kg^{-1}). The main physicochemical properties of root zone soil (0–80 cm) are listed in Table 1. The alfalfa cultivar 'WL363HQ' was seeded on 22 September 2014 with a grain drill in rows with a row space of 0.3 m and a seed rate of 12.5 kg/hm^2. The spring green-up began on 22 March in 2016 and 25 March in 2017. The 3rd and 4th cutting in 2016 were harvested on 17 August and 27 September. The 3rd and 4th cutting in 2017 were harvested on 11 August and 20 September.

2.2. Experimental design

For evaluating the effects of methods and rates of urea application on NH_3 volatilization and alfalfa fine root growth, the experiment was conducted using a randomized complete block factorial design with three urea (urea with 46% N) application methods, four N application rates and three replications. The three N application methods consisted of shallow banding at 5 cm of soil depth, surface broadcasting and center-pivot fertigation. Banding was done by placing urea granules into a furrow at the center of the two rows of alfalfa (Fig. 1). The urea application rates were 69.0 (N1), 48.3 (N2), 27.6 (N3) and 0 (N0) kg hm^{-2}. The plots of N0 and others (N1, N2, N3) with the fertigation were placed in the first span and overhang irrigated area, respectively, with a plot size of 4 m × 4 m. The treatments of banding and broadcasting using split-plot-design were placed in the second and 3rd spans, respectively. Main plots were partitioned into four subplots that received four levels of fertilizer rates. The subplot dimensions were 4 m × 4 m and the layout are showed in Fig. 1. In the study, no urea fertilizer was applied during the former two cuttings. Urea fertilizer was only applied during the regrowth period of the 3rd and 4th harvest to compensate nitrogen consumption by the last harvest of alfalfa. Urea fertilizer was applied with the first irrigation event for the 3rd and 4th cuttings. Specially, urea fertilizer was applied on 10 July and 25 August in 2016; and on 10 July and 17 August in 2017, respectively.

Table 1
Soil physicochemical properties at experimental site.

Depth (cm)	Bulk Density (g/cm^3)	Saturated soil moisture content (cm^3/cm^3)	Field capacity (cm^3/cm^3)	$NH4^+$-N content (mg/kg)	$NO3^+$-N content (mg/kg)	pH
0–20	1.62	0.39	0.23	7.65	2.35	7.9
20–40	1.61	0.39	0.23	6.54	2.38	8.0
40–60	1.50	0.41	0.21	6.81	2.32	8.0
60–80	1.47	0.41	0.21	4.95	2.38	8.0

2.3. Fertilizer system and irrigation scheduling

The fertigation urea solution was applied by a fertigation system integrated into a center-pivot which allowed application of the solubilized urea with the irrigated water. The fertigation system consists of a fertilizer storage tank with a volume of 2000 L and a piston injection pump with a flow rate of 260 L h^{-1}. The storage tank was equipped with a standing pipe that allowed volumetric calibration of the flow rate of the injection pump. The urea fertilizer solution was sprayed into the field by the center pivot system with the irrigation water. A center pivot irrigation system (model DYP, Modern Agricultural Equipment Co., Ltd, Beijing, China) with R3000 sprinklers and 20 psi (138 kPa) pressure regulators were used in this study. The irrigation system had three spans and an overhang with a length of 15.0 m. The lengths of spans were 37, 38 and 50 m for first, second and 3rd span, respectively. Each sprinkler was independently controlled by solenoid valves installed between each drop pipe and lateral pipe. The uniformity coefficient of the center pivot system used in this study was 89.64% (Yan et al., 2015). Fertilization was manually applied for the plots of banding and broadcasting methods and then immediately irrigated by a pipe. Irrigation was scheduled by crop evapotranspiration (ET_C), which was calculated by reference evapotranspiration (ET_O) and crop coefficients (K_c). ET_O was calculated using the data collected from a portable weather station in the alfalfa field based on the Penman-Monteith approach (Allen et al., 1998). Daily K_c was generated using FAO-56 (Allen et al., 1998), with the calculated parameters and actual growing period lengths adjusted to the NCP. In the calculation, K_c values were allowed to increase linearly from 0.5 to 1.23 and remained at 1.23 until harvest in each cutting. Irrigation in this study was scheduled based on soil water depletion. Irrigations for all plots were applied when the volumetric water content (VWC) of the topsoil layer (0–20 cm) reached 60% of the field capacity (0.14 cm^3 cm^{-3}). All plots received the same irrigation depth during the whole growth period of alfalfa. In the first irrigation event for the 3rd and 4th cuttings, the plots received 30 mm of irrigation water. The whole field was irrigated by the center pivot irrigation system in the former two cuttings, with the total irrigation amounts of 158 and 147 mm in 2016 and 2017, respectively. For the 3rd and 4th cutting, the plots of banding and broadcasting were irrigated with pipe irrigation system while the rest of field were irrigated with the center pivot system. The total irrigation amounts were 30 mm for the 3rd cutting and 78 mm for the 4th cutting in 2016. The 39 mm for the 3rd cutting and 43 mm for the 4th cutting occurred in 2017.

2.4. Measurement parameters

2.4.1. Weather data

Precipitation, air temperature and relative humidity were collected by a portable weather station (WatchDog2900ET, SPECTRUM, USA) installed in the study field.